

California High-Speed Train Project



TECHNICAL MEMORANDUM

Pantograph Clearance Envelopes

TM 3.2.3

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Released by: Signed document on file 10 Aug 09
Anthony Daniels, Program Director Date

Revision	Date	Description
0	17 July 09	Initial Release

Note: Signatures apply for the latest technical memorandum revision as noted above.

Prepared by 
for the California High-Speed Rail Authority

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System Level Technical Reviews by Subsystem:

Systems: *Signed document on file* 30 May 08
Eric Scotson Date

Infrastructure: *Signed document on file* 18 May 08
John Chirco Date

Operations: *Signed document on file* 2 Jun 08
Paul Mosier Date

Maintenance: *Signed document on file* 2 Jun 08
Paul Mosier Date

Rolling Stock: *Signed document on file* 28 May 08
Frank Banko Date

Note: Signatures apply for the technical memorandum revision corresponding to revision number in header and as noted on cover.

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ABSTRACT

The California High Speed Train Project (CHSTP) will provide high-speed train service in the state of California with proposed terminal stations (end-of-line or end-of route) in Sacramento, San Francisco, Fresno, Bakersfield, Los Angeles, Anaheim and San Diego. Intermediate stations will serve locations along the alignment. For much of the alignment, high speed trains will operate along a dedicated track with stations that exclusively serve high speed train operations at 350 Km/h (220mph). There are also two locations (the Lossan and Caltrain corridors) where the proposed California High-Speed Rail (CHSR) line will operate within a shared right-of-way permitting a maximum speed of 125mph(201Km/h) with conventional passenger railroad lines.

The purpose of this technical memorandum is to review best practice and provide design criteria for the pantograph clearance envelopes to:

- Ensure safe clearances to pantographs as well as to the overhead contact system support structures in all rights of way in which the California High Speed Train (CHST) will operate
- Clearly define facility design parameters
- Minimize existing structures design restrictions

Development of the design criteria for pantograph clearance envelopes will include review and assessment of, but not be limited to, the following:

- Existing FRA, State of California General Orders, NESC, IEEE and NFPA guidelines where applicable to pantograph clearance envelopes
- Existing international standards, codes, best practices and guidelines used on existing High Speed Train Systems for applicability to the CHSTP.

As the Overhead Contact System for High Speed Trains has unique requirements for safe and efficient operations at high speeds, this memorandum will define the pantograph clearance and catenary space required for the sections of the CHSTP dedicated to high speed train operation only , e.g. up to 350 Km/h (220mph), and for the right of ways shared with conventional passenger trains, namely the Lossan and Caltrain shared use corridors where the speed will be lower, e.g. up to 125mph(201Km/h).

The current design practice for High-speed train pantograph gauges and electrical envelope of the OCS presently in operation throughout the world are considered in the development of the pantograph envelopes for the CHST project, and are referenced where appropriate.

The design criteria developed in this Technical Memorandum are developed on the basis of the Technical Memorandum ref. TM 1.1.10 "Structure Gauge" which provides the static gauge, dynamic gauge and structure gauge of the high speed vehicles that are likely to be used on the sections of the CHSTP dedicated to high speed operation only, and the envelope of the static gauge, dynamic gauge and structure gauge of both the high speed vehicle and American passenger cars that will both operate in shared use corridors.

From this basis, the design defines a contact wire height for high speed dedicated sections that will be used by high speed vehicle gauge only and another contact wire height for shared use corridors above tracks where both high speed vehicle gauge and American passenger car gauge are to be considered. It does not however consider the contact wire height for the rolling stock depot / yard in which specific inspections and safety considerations for maintenance personnel may require other contact wire heights above dedicated specific maintenance tracks.

"Safety clearances" related to the height of the overhead contact system such as clearances of 25kV live parts above station platforms, or minimum heights of conductors above walkways or other accessible areas are not addressed in this document as they are provided in the "OCS Requirements" Technical Memorandum.

1.0 INTRODUCTION

1.1 Purpose of Technical Memorandum

The purpose of the technical memorandum is to set forth design criteria related to pantograph clearance envelopes together with the total vertical clearance required for the Overhead Contact System between two supports in order to:

- Ensure safe clearances to pantographs as well as to the overhead contact system in all rights of way in which the CHST will operate
- Minimize existing structures design restrictions and sizes of tunnel/underpass in an effort to reduce construction costs
- Clearly define facility design parameters

It will thus promote safe and efficient operations for high-speed rail train service on both the segments of the California High Speed Train Project (CHSTP) alignment that are dedicated to very high speed and for those in shared use operation.

This memorandum presents data relating to the design of pantograph clearance envelopes and vertical space for the overhead contact system acceptable for high-speed train operation. Where available, it is based on worldwide present practice and on present U.S. Federal and State Orders, guidelines and practices. Document searches were conducted to identify definitive criteria to be used for the CHST project application and, in some cases, data was not available. Present practices for high speed railways were reviewed and used to define criteria for the CHST project that is incorporated in this memorandum.

This memorandum is intended to be used by the Regional Engineering Consultants in developing the design of the right of way, especially regarding dimensioning of structures.

It is anticipated that the design will be advanced consistent with applicable codes of practice, design guidelines and other information that defines the CHSTP programmatic, operational, and performance requirements. Additional guidance on the vehicle clearances and on Overhead Contact System requirements to be used for high speed train operations will be transmitted in separate documents.

Following review, specific guidance in this technical memorandum will be excerpted for inclusion in the CHSTP Design Manual.

1.2 STATEMENT OF TECHNICAL ISSUE

The pantograph envelope is an important criteria to define the required safe clearances to the overhead contact system as well as to the pantographs of vehicles. Together with the vehicle clearance envelopes or vehicle structure gauges which are defined in a separate Technical Memorandum, the pantograph envelopes and OCS electrical envelopes will permit to safely minimize structures dimensions so as to ensure safe operation at maximum speed, of vehicles together with their pantograph.

There are three types of pantograph envelopes, namely:

- the static gauge of the pantograph,
- the dynamic envelope of the pantograph which takes into account the sway and uplift of the pantograph when running at high speed, and
- the electrical envelope of the pantograph which takes into account the dynamic electrical clearance on top of the dynamic envelope.

No part of the overhead contact system equipment shall be within the dynamic pantograph envelope and no earthed part shall be within the electrical pantograph envelope.

The dimensions of the dynamic pantograph envelope are depending on the pantograph static gauge, on the uplift of the pantograph which increases as the speed increases, and on the pantograph sway (that includes the dynamic movement of the vehicle and pantograph, the effect of curvature on the centreline of the envelope, and for track maintenance tolerance) which increases in curved super-elevated track and which increases proportionally as the height of the contact wire increases.

However, to have a design of overhead contact system equipment which remain compatible with existing proven equipment, and therefore to avoid elements in the catenary system that are not of proven design, it is important to properly dimension the pantograph envelope.

Also, to have a cost effective design of the structures and right of way fixed proven equipment, it is important to use the gauges of only the pantographs that are or will potentially travel on the right of way and to not to over dimension the vehicle clearance envelope.

It is therefore necessary to determine the safe maximum envelope corresponding to both, the different pantographs that could be running on the California High Speed line, and the different situations of track alignment and traffic that could be encountered (i.e. in the shared use corridors for a maximum speed of 125mph and on the right of way dedicated to very high speed train).

In addition, the electrification in 2x25 KV – 60 Hz of the California High Speed Train Project requires a clearance space of which the vertical and horizontal dimensions are safely dimensioned to permit the installation of the catenary of the Overhead Contact System, including wires and hardware, and cater for the necessary electrical clearances between any structure and live parts of the overhead contact system and pantograph. However, for a 2x25kV electrification system as will be used for the CHSTP, additional space and requirements that will be required for the longitudinal negative feeder (-25kV) associated with the (25kV) catenary will be addressed and transmitted in separate documents. Also, requirements at specific locations where insulated overlaps and crossovers and turnouts are installed, are not covered by this technical memorandum and will be addressed in separate documents or drawings.

1.3 GENERAL INFORMATION

The general basis for design standards will be the most applicable of the “recommended practice” described in the Manual for Railway Engineering of the American Railway Engineering and Maintenance of Way Association (AREMA Manual). The material presented in the AREMA Manual varies considerably in level of detail and applicability. Therefore, a reference to the AREMA Manual without a more specific designation of applicable chapter and section is not sufficient to describe any requirement.

In addition, for the vehicle clearance criteria, the PUC General Order 26-D of the State of California governing clearances on railroads and street railroad with reference to side and overhead structures, is being used for the design basis.

Also, for both the segments of the California High Speed Train Line that are dedicated to very high speed and for those in shared use operation, international standards and guidance's, especially those related to high speed lines, will be taken into consideration such that proven high speed line design is incorporated in the basis of the CHSTP design.

1.3.1 DEFINITION OF TERMS

The following technical terms and acronyms used in this document have specific connotations with regard to California High Speed Train system.

Shared Use Corridor - Segment along the CHSTP alignment where high speed trains share ROW with other passenger railroads, i.e. Caltrain, MetroLink, and Amtrak

Shared Use Track - Segment along the CHSTP alignment where high speed trains operate with other passenger railroads, i.e. Caltrain, MetroLink, and Amtrak, on the same tracks.

<u>Dedicated Corridor</u> -	Segment along the CHSTP alignment where high speed trains operate exclusive of other passenger railroads.
<u>Interoperability</u> -	In the context of the European High Speed Lines, is the aptitude of the European High Speed lines railway network to allow high speed trains to run safely and continuously with the specified performances. It is based on the whole of the legal, technical and operational conditions that must be fulfilled to satisfy to the necessary requirements. Thus, for example, a German high Speed train satisfying to the requirements of the Rolling Stock Technical Specification for Interoperability (TSI) is able to run safely and continuously on a French High Speed Line of which the infrastructure is satisfying to the different requirements of the different infrastructure Technical Specifications for Interoperability. These TSI design standards were developed specifically for the design, construction and operation of interoperable high-speed railways in Europe and are based on European and international best practices.
<u>Superelevation</u> -	The difference in elevation between the outside rail of the curve and the inside rail of the curve measured between the highest point on each rail head. Normally called Cant in European publications.
<u>Equilibrium Superelevation</u> -	The calculated superelevation that exactly balances the lateral force of the train on the curve at the defined speed. Normally called Balancing Cant or Equilibrium Cant in European publications.
<u>Unbalance, Unbalanced Superelevation</u> -	The difference between the Superelevation and Equilibrium Superelevation. In European publications, Unbalance is called Cant Deficiency if the actual Superelevation is less than the Equilibrium Superelevation and Excess Cant if the actual Superelevation is greater than the Equilibrium Superelevation.
<u>Catenary</u> -	An assembly of overhead wires consisting of, at a minimum, a messenger wire, also called catenary wire, supporting vertical droppers (hangers) that support a solid contact wire which is the contact interface with operating electric train pantographs
<u>Dynamic Envelope of Pantograph</u> -	A clearance envelope around the pantograph static profile that takes into account under dynamic situation the pantograph sway and pantograph uplift
<u>Electrical clearance</u> -	Minimum clearance between live parts of either the OCS or a vehicle pantograph and grounded (earthed) parts of a fixed structure or a vehicle
<u>Electrical clearance – dynamic (passing)</u> -	Minimum clearance between live parts of either the OCS or a vehicle pantograph and grounded (earthed) parts of a fixed structure or a vehicle during the passage of an electrically powered vehicle equipped with a pantograph
<u>Electrical clearance – static</u> -	Minimum clearance between live parts of either the OCS or a vehicle pantograph and grounded (earthed) parts of a fixed structure when not subjected to the passage of an electrically powered vehicle equipped with a pantograph
<u>Equilibrium Superelevation</u> -	The calculated superelevation that exactly balances the lateral force of the train on the curve at the defined speed. Normally called Balancing Cant or Equilibrium Cant in European publications.
<u>Interoperability</u> -	In the context of the European High Speed Lines, is the aptitude of the European High Speed lines railway network to allow high speed trains to run safely and continuously with the specified performances. It is based on the whole of the legal, technical and operational conditions that must be fulfilled to satisfy to the necessary requirements. Thus, for example, a German high Speed train satisfying to the requirements of the Rolling Stock Technical Specification for Interoperability (TSI) is able to run safely and continuously on a French High Speed Line of which the

infrastructure is satisfying to the different requirements of the different infrastructure Technical Specifications for Interoperability. These TSI design standards were developed specifically for the design, construction and operation of interoperable high-speed railways in Europe and are based on European and international best practices.

<u>Live</u> -	An electrically energized circuit or component
<u>Live Part</u> -	A part or component connected to an energized circuit and therefore live as not insulated from the energized circuit.
<u>Pantograph</u> -	Device consisting of spring-loaded hinged arms fitted to the roof of a train that collects current from the contact wire of an overhead contact system
<u>Dynamic Envelope of Pantograph</u> -	A clearance envelope around the pantograph static profile that takes into account under dynamic situation the pantograph sway and pantograph uplift
<u>Pantograph sway (Pantograph lateral displacement)</u> -	Lateral displacement of the pantograph induced, under the dynamic passage of the electrical vehicle, by vehicle and pantograph lateral displacements that include gauge deviation, roll and lateral vehicle shock loads, and cross-track tolerance.
<u>Overhead Contact System (OCS)</u> -	Also called Overhead Catenary system. A system, part of the traction power electrification system, comprising overhead wires including the contact wire, messenger (or catenary) wire, auxiliary wires, supports, poles, foundations, balance weight arrangements, electrical switches and isolators, and other equipment and assemblies, and that delivers electric power from a traction power substation to rail vehicles operating beneath the overhead wires.

Acronyms

AAR	Association of American Railroads
AREMA	American Railway Engineering and Maintenance of Way Association
Caltrans	California Department of Transportation
CHSRA	California High Speed Rail Authority
CHST	California High Speed Train
CHSTP	California High Speed Train Project
CFR	Code of Federal Regulations
FRA	Federal Railroad Administration
GO	General Order
PUC	Public Utilities Commission of the State of California
SCRRA	Southern California Regional Rail Authority
SNCF	Société Nationale des Chemins de fer Français (French National Railway Company)
TSI	Technical Specification for Interoperability of European High Speed Lines
UIC	International Union of Railways (Union Internationale des Chemins de Fer)

2.0 DEFINITION OF TECHNICAL TOPICS

2.1 GENERAL

Design criteria related to pantograph clearance envelopes together with the total vertical clearance required for the Overhead Contact System, excluding its associated longitudinal -25kV feeder, are an integral part of the design and particularly of the overhead contact and structures design, but other design elements must also take into account these criteria so as to not hamper train circulation and pantograph passage.

It is anticipated that the type of rolling stock for the CHSTP together with the pantograph type and the Overhead Contact System will not be selected prior to the completion of the 30% Design Level (Preliminary Engineering). Accordingly, the design guidelines included in this document are intended to accommodate the CHSTP preliminary engineering needs without precluding any potential high speed system technology. The design is conducted with the assumption that the high speed train sets technologies together with the high speed pantographs and the high speed overhead contact system that can most likely meet the CHSTP performance requirements will be those of the French (Alstom – AGV), Japanese Shinkansen (Hitachi- N700), German (Siemens - ICE 3 - Velaro E) and Bombardier (AVE S-102). Refinements in the design and associated design elements will be required following vehicle and pantograph, and overhead contact system selection.

2.2 LAWS, CODES AND STANDARDS

2.2.1 NORTH AMERICAN RECOMMENDED PRACTICE AND LEGAL REQUIREMENTS IN CALIFORNIA

AREMA Manual

The primary orientation of the American Railway Engineering and Maintenance of Way Association (AREMA Manual) is to provide guidance in the engineering of railroads moving freight at speeds up to 70 mph and passenger trains at speeds up to 90 mph with the exception of the still incomplete Chapter 17, High Speed Rail Systems.

The material presented in the AREMA Manual varies considerably in level of detail and applicability. Therefore, a reference to the AREMA Manual without a more specific designation of applicable chapter and section is not sufficient to describe any requirement.

When using the AREMA Manual, the statement at the beginning of each chapter will assist in understanding the scope, intent, and limitations of this document.

"The material in this and other chapters in the AREMA Manual for Railway Engineering is published as recommended practice to railroads and others concerned with the engineering, design and construction of railroad fixed properties (except signals and communications), and allied services and facilities. For the purpose of this Manual, RECOMMENDED PRACTICE is defined as a material, device, design, plan, specification, principle or practice recommended to the railways for use as required, either exactly as presented or with such modifications as may be necessary or desirable to meet the needs of individual railways, but in either event, with a view to promoting efficiency and economy in the location, construction operation or maintenance of railways. It is not intended to imply that other practices may not be equally acceptable."

Legal requirements in California

At present, legal rules for Overhead Electric Line Construction are defined in PUC GO 95 and legal minimum clearances around railroad tracks in California are defined in PUC GO 26-D. The requirements of these General Orders shall govern regardless of lesser dimensions in other standards or guidelines.

2.2.2 CHSTP DESIGN CRITERIA APPLICABLE PANTOGRAPH CLEARANCE AND FOR THE TOTAL VERTICAL CLEARANCE REQUIRED FOR THE OVERHEAD CONTACT SYSTEM

There is no existing law, code, or design standard applicable for the design of high speed lines in the United States of America. Accordingly, the development of the CHSTP design criteria applicable for pantograph clearance and for the total vertical clearance required for the Overhead Contact System, was based on a review and assessment of available information, including the following:

- AREMA Manual
- California Public Utilities Commission General Orders 95 and 26-D
- Amtrak guidelines and present practices
- Federal and State Orders guidelines and present practices
- Caltrain Design Criteria (April 15, 2007)
- Technical Specifications for Interoperability of European High Speed lines

The AREMA Manual can be referenced for guidance as follow:

Section 1.8 of Chapter 28 of the AREMA manual recommends for the overhead electrification that an overhead clearance of 24'-3"(7392mm) above top of rail in tangent tracks should be provided for a 25kV line.

In addition, Part 2 "Clearances" of Chapter 33 "Electrical Energy Utilization" of the AREMA manual can be referenced for guidance for on recommended clearance for overhead electrification and for additional vertical and lateral space requirements above the contact wire height.

Also, it is recommended in Part 4 of Chapter 33 of the AREMA Manual, to use a contact wire height of 23'-0"(7010 mm) above top of rail.

However, Section 1.8 of Chapter 28 and Parts 2 and 4 of Chapter 33 of the AREMA Manual do not address high speed or very high speed.

The requirements of the specific provider of the train sets, pantograph and electrification technologies that are likely to be used for the CHSTP may differ. This is why guidelines provided by the Technical Specifications for Interoperability of European High Speed lines (TSI) are also referenced since these design standards were developed specifically for the design, construction and operation of interoperable high-speed railways in Europe and are based on European and international best practices.

A listing of references considered in preparation of this memorandum is included in Section 6.0.

In the case of differing values, or conflicts in the various requirements for design, conflicts between any of them, or following design guidelines, and until such time that the CHSTP high speed system technology is selected, the standard followed shall be that which results in the highest level of satisfaction for all requirements without precluding any potential high speed system technology or that is deemed as the most appropriate by the California High-Speed Rail Authority (CHSRA). The standard shall be followed as required for securing regulatory approval.

2.3 VEHICLE GAUGES AND PANTOGRAPH ENVELOPES

2.3.1 VEHICLE GAUGES

The Technical Memorandum TM 1.1.10 "Structure Gauge" provides the envelopes of the static gauges, dynamic gauges and structure gauges of both the high speed vehicle and American cars that are likely to be used on the sections of the CHSTP that are dedicated to high speed operation and on the sections of the CHSTP that are shared use corridors.

For sections of the CHSTP that are dedicated to high speed operation, based on the assumption that the high speed train sets technology that would likely be used for the CHSTP will be either the Siemens - ICE

3 (Velaro E), the Shinkansen - 700T, the Bombardier - AVE S-102 or the Alstom – AGV, the maximum dimensions of the static gauge are a maximum width of 11'-9.7"(3600 mm) and a maximum height above top of rail of 14'-9.2"(4500 mm).

Thus, on the line sections dedicated to high speed train only, the maximum height of 14'-9.2"(4500 mm) of the static gauge of the high speed trains will be considered for determining the nominal contact wire height of the overhead contact system.

For shared use corridors, based on that assumption that the maximum dimensions of the American passenger car static gauge are those of the new Caltrain car which corresponds to a widened Plate F outline, the maximum dimensions of the static gauge are a maximum width of 11'-0"(3352 mm) and a maximum height above top of rail 17'-0"(5182 mm).

Thus, for shared use corridors, the maximum height of 17'-0"(5182 mm) of the static gauge of the Plate F American passenger car will be considered for determining the nominal contact wire height of the overhead contact system.

US freight trains of the Plate H dimensions (used for double stack containers, tri-level container stacks, and tri-level auto carrier) that are higher than the typical passenger car gauges, will only be considered for the design of the shared use corridors for non electrified tracks adjacent to electrified tracks. Indeed, electrified tracks either dedicated to high speed trains or shared for high speed trains and local passenger trains will not be used for freight traffic.

As explained in the Technical Memorandum TM 1.1.10 "Structure Gauge", the design has to take into account the "Dynamic Vehicle Outline", also called "Kinematic Vehicle Gauge" which takes into account, on top of the static gauge, the dynamic movements of a car (shift, sway and bounce) as it travels along the track, as well as the structure gauge that takes into account on top of the dynamic vehicle gauge, adjustments required for the effect of curvature on the centerline of the envelope, as well as for the horizontal and vertical normal shifts track location so as to ensure no potential obstruction to the passage of a car.

For a variety of reasons, railway engineers do not design and build tunnels and other structures to the gauge dimensions of a specific vehicle. Whether for an upgraded or for a newly-constructed tunnel, the design requirements incorporate instead various adjustments for lateral clearances and vertical clearances.

In particular concerning the vertical clearances, the design shall consider the space that is required for the pantograph envelope and for the 25kV catenary, as well as for its associated longitudinal negative feeder.

2.3.2 PANTOGRAPH ENVELOPES AND SPACE FOR OVERHEAD CONTACT SYSTEM

The 2x25 kV – 60 Hz overhead electrification of the California High Speed Train Project requires vertical and horizontal adjustments to the required clearances beyond those used in non-electrified railroads. The total vertical clearance required for electrification is to be added to the car gauge dimension to allow for a number of factors:

- The electrical clearance between the contact wire and loading gauge
- The pantograph clearance envelope that takes into account, at the contact wire height considered, the horizontal dynamic movement (sway) and vertical movement (uplift) of the pantograph when the vehicle is running at maximum speed;
- The electrical clearance between the structure and live parts of the overhead contact system and pantograph;
- The depth of the catenary, including wire and hardware and the construction and maintenance engineering tolerances.

2.3.2.1 CHSTP DESIGN CONSIDERATIONS

For the pantograph envelope and space required for the Overhead Contact system of the California High Speed Line, the following considerations are taken into account:

- As the width of the pantograph envelope increases with the contact wire height, the design will consider a dedicated maximum pantograph envelope for the line sections dedicated to high speed train only where the contact wire height can be safely optimized at a reasonably low height.
- For the shared use corridors where local passenger trains will continue to be running either on the same track and/or on adjacent tracks that the tracks used by the high speed train and where the speed will be limited to 125 mph(201Km/h), the design will consider a maximum pantograph envelope dedicated to the shared use corridor. The pantograph envelope dedicated to the shared use corridor will consider a limited uplift due to the maximum speed of the corridor section, but a larger sway due to the higher contact wire because of the shared use of high speed train with local passenger trains that have a higher vertical dimension.
- The design will not consider a pantograph envelope for electrification of tracks used by Plate H freight trains, as freight trains will run in shared use corridors temporally separated, and/or on non electrified tracks adjacent to tracks either dedicated to high speed train only or dedicated to both high speed train and local passenger trains.
- The design will consider the space required for the High Speed catenary on sections of the line dedicated to high speed train running at 220mph (350Km/h). The design will also consider the space required for the catenary on shared use corridors for a maximum speed of 125 mph(201Km/h) for which the vertical space can be reduced/optimized compared to the space required for very high speed, so as not to over dimension the design of right of way structures (tunnel, bridges) for shared use corridors. However, for a 2x25kV electrification system as will be used for the CHSTP, additional space and requirements that will be required for the longitudinal negative feeder (-25kV) associated with the (25kV) catenary will be addressed and transmitted in separate documents. Also, requirements at specific locations where insulated overlaps and crossovers or turnouts are installed, are not covered by this technical memorandum and will be addressed in separate documents or drawings.
- In addition, the design will consider the guidelines of Section 1.8, Part 1 of Chapter 28 of the AREMA Manual, and of Part 2 and Part 4 of Chapter 33 of this AREMA Manual.

2.3.2.2 CHSTP DESIGN PARAMETERS

The design parameters that are relevant to the vehicle and pantograph clearance envelope for California High Speed Train Project are the following:

- Vehicle gauges and clearance plates for the different vehicles that would travel on the CHSTP line, either on the whole route or on the shared use corridors only.
- Track curve values with corresponding maximum superelevation for the shared use corridors of the CHSTP.
- Track curve values with corresponding maximum superelevation for the high speed sections of the CHSTP.
- Maximum pantograph static gauges that would be used on the CHSTP line.
- Static and dynamic / passing 25kV electrical / air clearances.
- Other relevant Overhead Contact System design parameters such as contact wire heights, uplifts, system heights and construction tolerances.

3.0 ASSESSMENT / ANALYSIS

3.1 GENERAL

Vehicle static gauge data applicable to high speed train set cars, as well as equipment diagrams for American conventional passenger trains, together with American and international applicable standards or guidelines were collected along with the CHSTP track characteristics design criteria that are applicable for sections of the CHSTP dedicated to high speed operation only and for sections of the CHSTP that are shared use corridors for both high-speed trains and conventional passenger trains.

Data applicable to pantograph gauges and overhead contact systems used overseas for existing high speed railways, as well as vehicle gauge data applicable to high speed train set cars American conventional passenger trains (see Technical memorandum TM 1.1.10 "Structure Gauge") together with American and international applicable standards or guidelines were collected along with the CHSTP track characteristics design criteria that are applicable for sections of the CHSTP dedicated to high speed operation only and for sections of the CHSTP that are shared use corridors for both high-speed trains and conventional passenger trains.

From those data, the following design assessment has been considered as guiding criteria for the pantograph clearances and for the vertical space required for the overhead contact system for the CHSTP.

3.2 GENERAL ANALYSIS FOR THE DETERMINATION OF THE PANTOGRAPH ENVELOPES AND SPACE NECESSARY FOR THE OVERHEAD CONTACT SYSTEM

In order to define the space required for the passage of pantographs, and further more the vertical space required for the overhead contact system for the CHSTP, it is necessary to proceed as follows:

- Step No 1: Identify, based on the AREMA Manual recommended pantograph dimension and on the assumption of the high speed train sets technologies that would likely be used for the CHSTP, the existing different pantograph static gauges that would travel on the CHSTP very high speed line, and create as a result a pantograph combined static gauge to be used for the CHSTP,
- Step No 2: Determine using the appropriate rule for the determination of sway, and using the applicable track data characteristics and best assumption on the contact wire heights to be used for the CHSTP, the resulting pantograph combined dynamic gauge and resulting pantograph clearance envelopes applicable for the CHSTP. These envelopes will be determined for the sections of the CHSTP dedicated to high speed operation only, and also for the sections of the CHSTP that are shared use corridors for both high-speed trains and conventional passenger trains,
- Step No 3: Determine, using appropriate data collected from high speed rail overhead contact systems currently in operation, the vertical space required for the CHSTP catenary, excluding its associated negative longitudinal feeder, on sections of the CHSTP dedicated to high speed operation only, and also on sections of the CHSTP that are shared use corridors for both high-speed trains and conventional passenger trains. It is to be noted that, if the catenary is always located above the track centreline (plus or minus the catenary stagger), the negative feeder in phase opposition with the catenary can be located in different locations according to different arrangements (e.g. track side of the OCS mast or country side of the OCS mast, above OCS portal structures, in tunnels vaults, etc.) as soon as the necessary electrical clearances between the negative feeder and the catenary and between the negative feeder and earth are respected. The space required by the negative feeder is therefore not covered in this document as it will be better described by OCS Standard drawings and the "OCS Requirements Technical Memorandum".

Step No 1:

The Japanese high speed lines are using a pantograph having a static gauge as shown below:

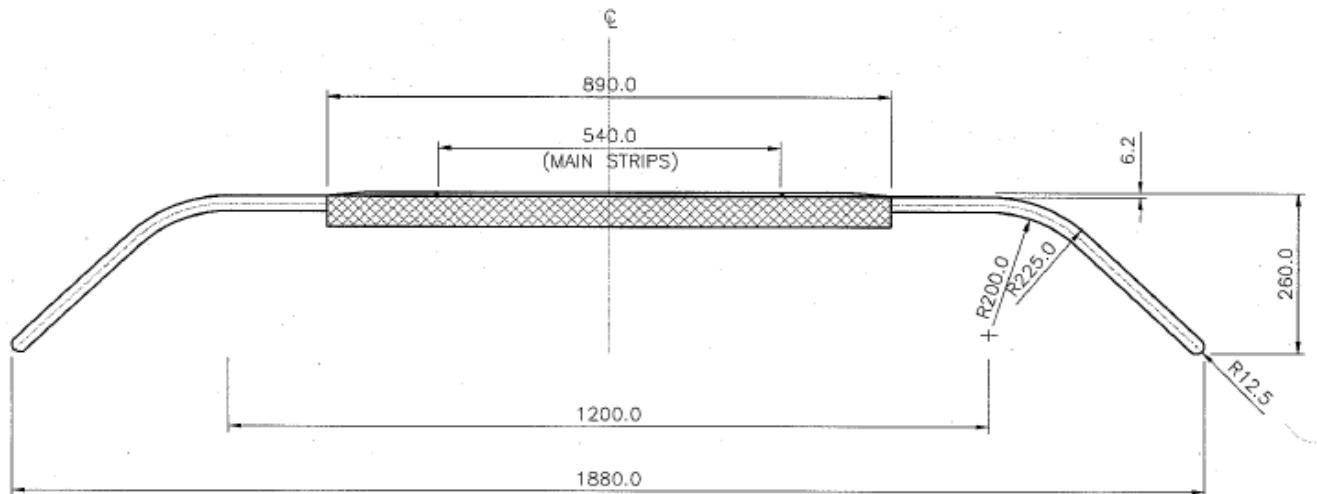


Figure 3.1 JAPANESE STATIC PANTOGRAPH GAUGE

The European high speed lines have standardized for interoperability purpose in Europe, the static gauge of the high speed train pantograph (applicable for Siemens, Alstom and Bombardier for the high speed train pantographs) which is a 5'-3"(1600mm) wide pantograph as shown below:

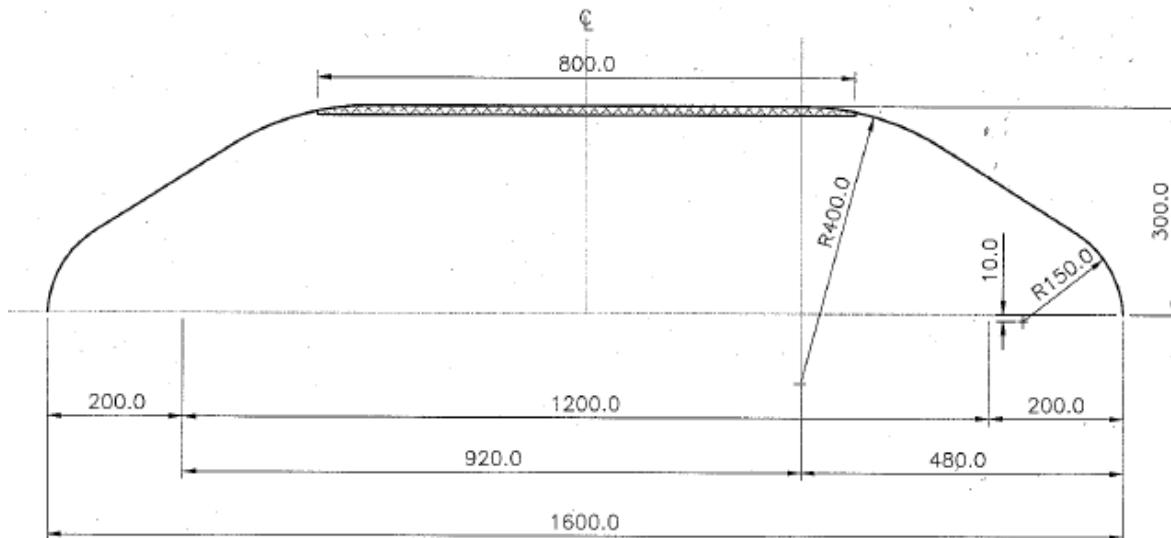


Figure 3.2 STATIC PANTOGRAPH GAUGE OF EUROPEAN INTEROPERABLE HIGH SPEED TRAIN SET

However Siemens are also using another wider pantograph for high speed train in Germany and abroad (for example in China) which is a 6'-4.8"(1950mm) wide pantograph as shown below:

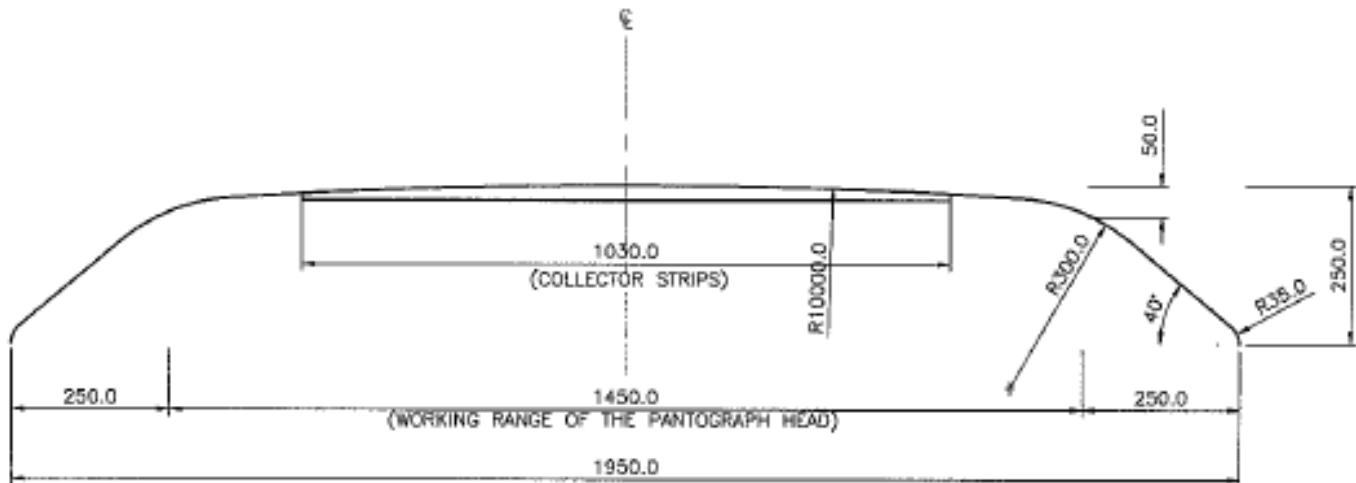


Figure 3.3 STATIC PANTOGRAPH GAUGE OF GERMAN HIGH SPEED TRAIN SET

As Chapter 33 of the AREMA Manual assumes a pantograph dimension of 6'-6"(1980mm) over the tips of the horn, which is exceeding by 1.2"(30mm) the widest pantograph profile of 6'-4.8"(1950mm) used in Germany, the design will consider this wider pantograph dimension of 6'-6"(1980mm) for the determination of the CHSTP pantograph envelope. It will not be used for pantograph security checks that consist, when calculating the maximum span lengths and staggers, in verifying that the contact wire will always remain on the pantograph working width or collector strip, and for which the smaller dimension of the pantograph collector strip will be considered).

The resulting pantograph combined static gauge to be used for the CHSTP is consequently as shown below:

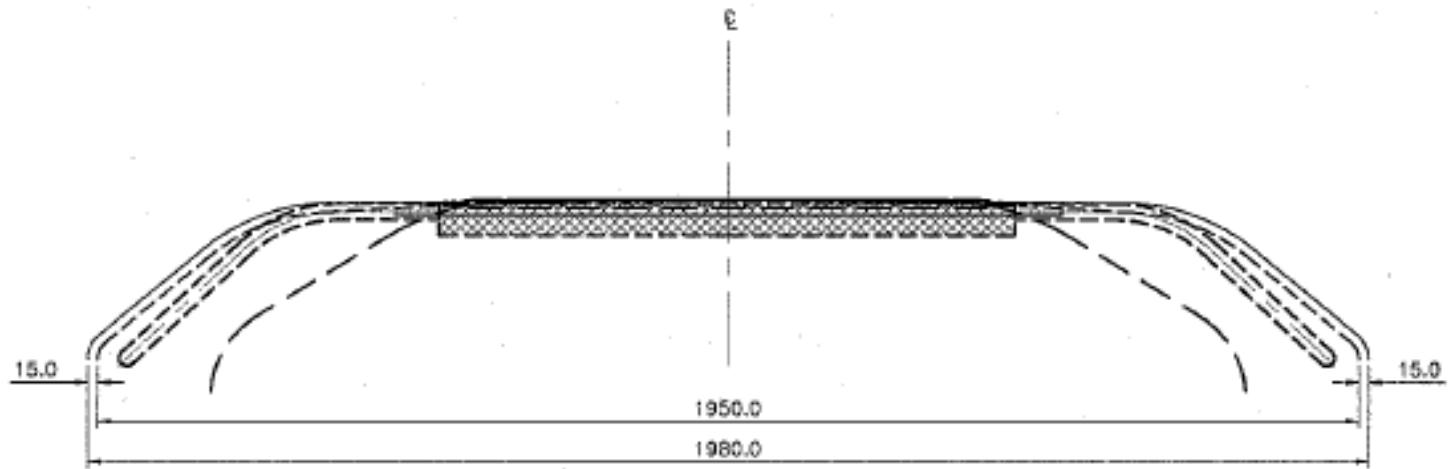


Figure 3.4 CHSTP COMBINED MAXIMUM STATIC PANTOGRAPH GAUGE

Step No 2:

Because of the impact of the contact wire height and track characteristics on the pantograph possible movement at the considered height, the analysis identifies two CHSTP sections, one section of the CHSTP dedicated to very high speed operation only, and the other sections of the CHSTP that are shared use corridors for both high-speed trains and conventional passenger trains.

For the section of the CHSTP dedicated to very high speed operation only:

- The CHSTP horizontal main track data characteristics for very high speed, as per the “Alignment Standards” Technical Memorandum, are for speeds above 125mph(201Km/h):

Minimum Curve Radii

Design Speed	Minimum Radius		
	Desirable	Minimum	Exceptional
250 mph (400 Km/h)	50,000 feet (15,000 m)	27,700 feet (8,300 m)	24,800 feet (7,500 m)
220 mph (350 Km/h)	37,900 feet (11,400 m)	21,500 feet (6,400 m)	19,300 feet (5,800 m)
200 mph (320 Km/h)	32,000 feet (9,700 m)	17,800 feet (5,300 m)	16,000 feet (4,900 m)
186 mph (300 Km/h)	27,900 feet (8,400 m)	15,500 feet (4,700 m)	13,900 feet (4,200 m)
170 mph (270 Km/h)	22,500 feet (6,800 m)	12,500 feet (3,800 m)	10,300 feet (3,100 m)
145 mph (230 Km/h)	16,400 feet (4,900 m)	9,100 feet (2,800 m)	7,500 feet (2,300 m)
125 mph (201 Km/h)	12,400 feet (3,700 m)	6,900 feet (2,100 m)	5,700 feet (1,700 m)

With the corresponding maximum superelevation values defined as:

- Desirable: 4"(100 mm),
- Maximum: 6"(150 mm) for $V < 186\text{mph}(300\text{ Km/h})$, and 7" * (180 mm) for $V \geq 186\text{mph}(300\text{ Km/h})$,
- Exceptional: 7" * (180 mm).

* Note: A value of maximum superelevation of 7"(180 mm) as taken for high speed and other passenger trains (as used in Europe and Japan) is thus considered for the determination of the sway of the pantograph in sections of the CHSTP dedicated to high speed for speeds above 125mph(201Km/h). The exceptional values of 6" (152 mm) superelevation and 1500' (457 m) curve radius are thus considered for the determination of the sway of the pantograph in sections of the CHSTP that are in share use for a maximum speed of 125mph(201 Km/h).

The contact wire height to consider is the one sufficient to allow for static and dynamic electrical clearances applicable above the vehicle static and dynamic gauges.

The maximum of the static gauge heights for the high speed train sets is 14'-9.2"(4500mm) for the Shinkansen, European and UIC gauge cars.

The standard contact wire height for the Shinkansen OCS is 16'-4.9"(50000mm) (with a minimum of 15'-9"(4800mm) and a maximum of 17'-0.7"(5200mm)). In Europe, the European Standard for interoperability of high speed trains requires the standard contact wire height to be between 16'-8"(5080mm) as mostly used, and 17'-4.7"(5300mm).

A minimum contact wire height of 16'-8.8"(5100mm) at support to determine the dynamic pantograph envelope on sections of the CHSTP dedicated to very high speed would therefore be sufficient to

remain compliant and as close as possible to the values used for high speed trains both in Europe and in Japan.

However, as the Germans are using on the Cologne-Rhine Main high speed line and in Spain, a contact wire of 17'-4.7"(5300mm) at support, we would determine the dynamic pantograph envelope on sections of the CHSTP dedicated to very high speed on the basis of this higher contact wire height of 17'-4.7"(5300mm).

- Based on experience on existing very high speed railway, the modelled, calculated or measured uplift S_o of the contact wire at its supporting steady arm location under normal operation condition at the maximum very high speed that is considered for the CHSTP is considered to be of up to 4.9"(125mm) at support*, whilst this uplift value can be increased up to 6.9"(175mm) in the span between two supports.

* Note: Once the overhead contact system together with high speed train set technology selected for the CHSTP, this value would have to be confirmed by the train set and OCS supplier.

For the CHSTP shared use corridors:

- The CHSTP horizontal main track data characteristics for sections of the CHSTP that are shared use corridors for both high-speed trains and conventional passenger trains, as per the "Alignment for Shared Use Operations" Technical Memorandum, are for speeds from 125mph(202Km/h) to 60mph(96 Km/h):

Minimum Curve Radii (*)

Maximum Superelevation	Unbalance	Design Maximum Speeds			
		125 mph (202Km/h)	100 mph (161 Km/h)	79 mph (127 Km/h)	60 mph (96 Km/h)
3" (76 mm)	3" (76 mm)	10,500 ft (3200 m)	6,500 ft (1981 m)	4,000 ft (1219 m)	2,500 ft (762 m)
4" (102 mm)	3" (76 mm)	9,000 ft (2743 m)	5,800 ft (1768 m)	3,600 ft (1097 m)	2,200 ft (671 m)
4" (102 mm)	4" (102 mm)	8,000 ft (2438 m)	5,000 ft (1524 m)	3,200 ft (975 m)	1,900 ft (579 m)
5" (127 mm)	3" (76 mm)	7,000 ft (2134 m)	4,500 ft (1371 m)	2,800 ft (853 m)	1,700 ft (518 m)
6" (152 mm)	3" (76 mm)		4,000 ft (1219 m)	2,500 ft (762 m)	1,500 ft (457 m)
6" (152 mm)	4" (102 mm)	6,500 ft (1981 m)	4,000 ft (1219 m)	2,500 ft (762 m)	1,500 ft (457 m)

* Note: Curves shall be not less than 1000 ft(305 m) where practical with an absolute minimum curve of 650 ft(198 m).

The contact wire height that is being considered is the one sufficient to allow for static and dynamic electrical clearances applicable above the highest of both the high speed vehicle and conventional passenger car static and dynamic gauges. The maximum of the static gauge heights is 17'-0"(5182mm) for a Plate F conventional passenger car (*) and thus, taking into account the necessary electrical air clearance between the top of the gauge and the contact wire height, the design could consider a standard minimum contact wire height of 18'-8.4"(5700mm) at support for sections of the CHSTP which are shared use corridors.

* Note: It is assumed that freight cars exceeding Plate F would not be allowed to run on the same electrified tracks that will be in shared use for high speed and conventional passenger vehicles.

- Based on experience on existing railways, the modelled, calculated or measured uplift S_o of the contact wire at its supporting steady arm location under normal operation condition at the maximum speed of 125 mph that is considered for sections of the CHSTP that are shared use corridors for both high-speed trains and conventional passenger trains, is of up to 3.9"(100mm) at support* (whilst we would consider an uplift value of up to 5.9"(150mm) in the span between two supports).

Step No 3:

The calculation of the space necessary for the passage of high speed train pantographs on the California High Speed Line is determined using the approach of the European Interoperable High Speed Line Committee.

From the dimension of the pantograph static gauge, are added laterally, dynamic clearance dimensions corresponding to the combined effects of the track geometry and pantograph contact height on the pantograph movement at the designed contact wire height.

The Figure below shows the dimensions for the space necessary for the passage of pantographs in which:

- S is the pantograph uplift value taken into account, under dynamic situation, for design.
 $S = 2 S_0$ where S_0 is the modelled, calculated or measured uplift of the contact wire at its supporting steady arm location under normal operation condition, and
- the width L_1 refers to the contact wire height of 16'-4.9"(5000mm) while L_2 depends on the contact wire height as applicable.

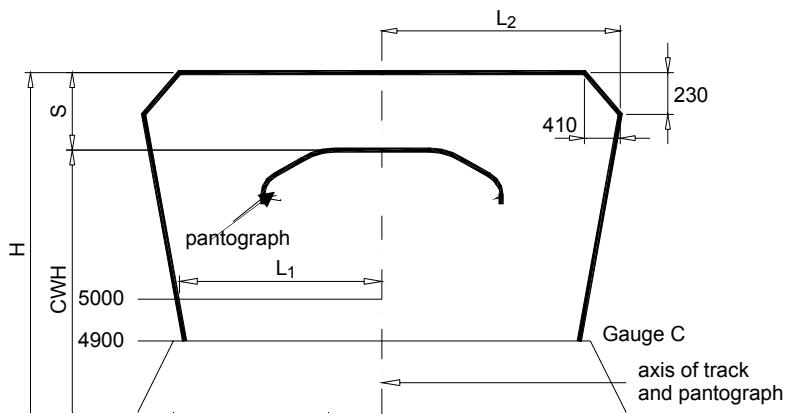


Figure 3.5 SPACE NECESSARY FOR THE PASSAGE OF PANTOGRAPHS

For the 5'-3"(1600mm) standardized wide pantograph gauge used for European high speed lines, the formula to determine the value L_2 is $L_2 = 0.74 + 0.04 H + 0.15 H C - 0.075 C + 2.5 / R$ (The unit of this formula is in meters), where H is the contact wire height considered, C is the superelevation and R is the curve radius.

For information, this formula is based on a more complex UIC formula for the determination of the sway value, where the off-centre value 'ep' of the pantograph bow is determined using lower and upper verification points resulting in known off-centre values for rolling stocks that are compliant with UIC parameters. This off-center value together with the effect of the oscillation of the vehicle at the contact wire height considered correspond to the term "0.04 H" in the formula. The term '0.15 H C - 0.075 C' corresponds to the effect of the superelevation and unbalance, and the term '2.5 / R' to the effects of the curve radius whilst the effect of 1.5cm track tolerance is taken into account in the constant term.

It is understood that Japanese rolling stock characteristics are compliant with UIC parameters, and thus the above STI formula to determine the value L_2 would also be applicable to Japanese pantograph.

For the combined CHSTP static pantograph gauge which is larger by 1'-3"(380mm) than the 5'-3"(1600mm) standardized wide pantograph gauge used for European high speed lines, the formula to determine the value L_2 will thus be $L_2 = 0.74 + 0.190 + 0.04 H + 0.15 H C - 0.075 C + 2.5 / R$ (The unit of this formula is in meters).

Consequently, with a contact wire height of 16'-8.8"(5100 mm) above top of rail and the CHSTP track characteristics for dedicated high speed sections, the space necessary for the dynamic passage of pantographs for the sections of the CHSTP dedicated to very high speed (with $L_2 = 4'-2.2"$ (1276mm) and $S = 9.8"$ (250mm) at support) is as shown below:

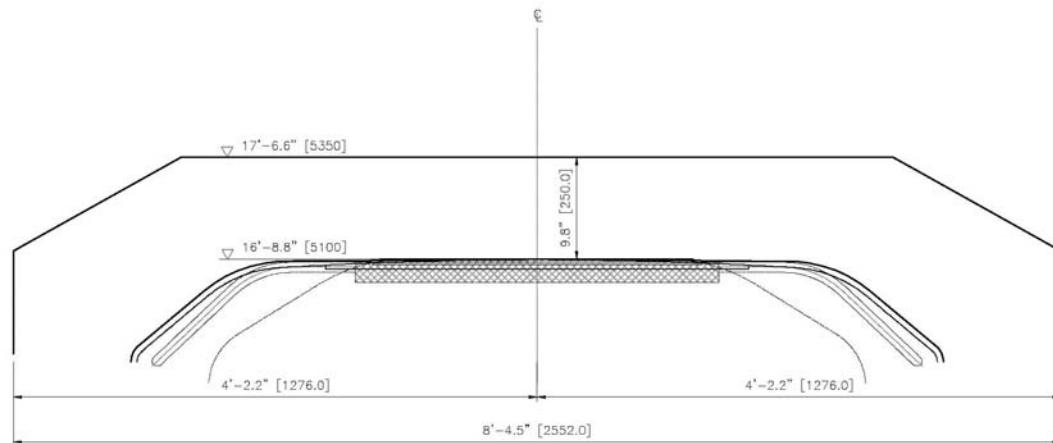


Figure 3.6 DYNAMIC ENVELOPE OF PANTOGRAPH FOR CHSTP SECTIONS DEDICATED TO HIGH SPEED FOR CONTACT WIRE HEIGHT OF 16'-8.8"(5100 mm)

And for a contact wire height of 17'-4.7"(5300 mm) above top of rail as used by the Germans on their Cologne-Rhine Main high speed line, and the CHSTP track characteristics for dedicated high speed sections, the space necessary for the dynamic passage of pantographs for the sections of the CHSTP dedicated to very high speed (with $L_2 = 4'-2.8"$ (1290mm) and $S = 9.8"$ (250mm) at support) is as shown below:

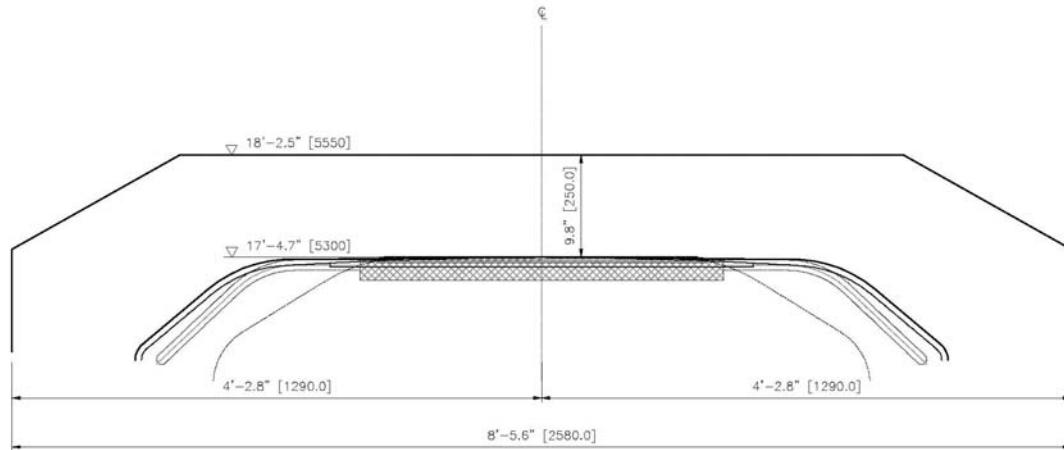


Figure 3.7 DYNAMIC ENVELOPE OF PANTOGRAPH FOR CHSTP SECTIONS DEDICATED TO HIGH SPEED FOR CONTACT WIRE HEIGHT OF 17'-4.7" (5300 mm) (IN ALIGNMENT)

Similarly, with a contact wire height of 18'-8.4"(5700 mm) above top of rail, that is 1'-8.4"(518 mm) above the top load gauge of the highest American passenger car used on shared use corridors of the CHSTP, and the CHSTP track characteristics for sections of the CHSTP that are shared use corridors for both high-speed trains and conventional passenger trains, the above TSI formula to determine, for high speed lines, the space necessary for the dynamic passage of pantographs would result in a total envelope width of 8'-6.4"(2600mm) (with $L_2 = 4'-3.2"$ (1300 mm) whilst $S = 7.9"$ (200mm)). However, on shared use corridors, for reduced speeds to a maximum of 125mph and with traffic of conventional passenger cars not having UIC rolling stock characteristics, the design considers the recommendation of Part 2 of Chapter 33 of the AREMA Manual where the width of the dynamic envelope is given by: $2Ss + X + E + 2L$, with:

- X is the static gauge pantograph width, (width of live portion of head). With reference to step 1 earlier, we use $X = 6'-6"$ (1980mm),
- Ss is the Locomotive or MU car sway. In accordance with the AREMA Tables 33-2-1 and 33-2-2, we use for a contact wire height of 18'-8.4"(5700 mm) plus 7.9"(200mm) uplift above top of rail and Class 6 track conditions, a sway value of $Ss=1'-6.1"$ (460mm) corresponding to the worst case of Multiple Unit cars.
- E is the Lateral allowance for superelevation. In accordance with the track characteristics for the shared use corridors, we use $E=1'-11.4"$ (594mm)
- L is the lateral shift of track that we take as 1"(25mm) maximum in accordance with the recommended AREAMA value,

Thus, the width of the dynamic envelope of the pantograph for shared use corridors, in accordance with the AREMA Manual is equal to 11'-7.6"(3545mm). The space necessary for the dynamic passage of pantographs for the sections of the CHSTP dedicated to very high speed (with a width of 11'-7.6"(3545mm) and an uplift of $S = 7.9"$ (200mm)) is as shown below:

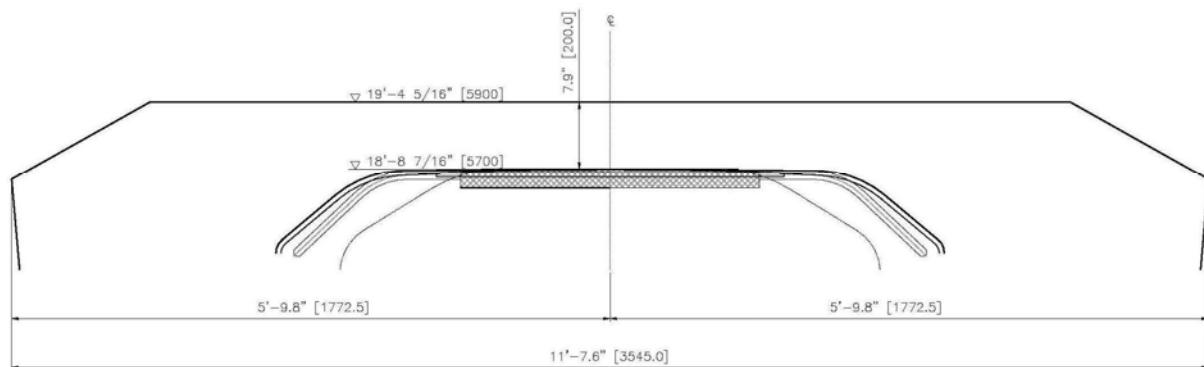


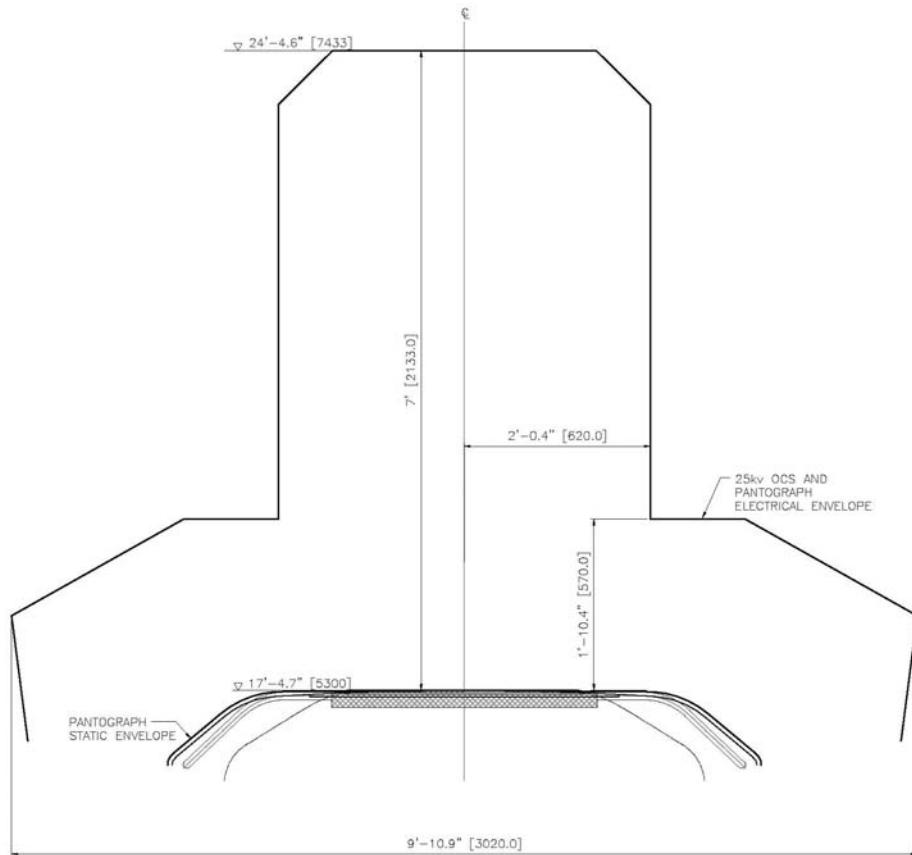
Figure 3.8 DYNAMIC ENVELOPE OF PANTOGRAPH FOR CHSTP SHARED USE CORRIDORS FOR CONTACT WIRE HEIGHT OF 18'-8.4"(5700 mm)

Note: It shall be noted that in Part 4 of Chapter 33 of the AREMA Manual, it is recommended to use a contact wire height of 23'-0"(7010 mm) above top of rail. However, Part 4 of Chapter 33 of the AREMA Manual does not address high speed. Indeed, such a contact wire height of 23'-0"(7010 mm) would allow for the passage of Plate H freight trains that are 20'-2"(6172 mm) high; but for the CHST project, Plate H freight trains would not be allowed to run on the same tracks than the electrified tracks that will be in shared use for high speed and conventional passenger vehicles. A height of 23'-0"(7010 mm) above top of rail is thus in excess of what is required and sufficient above top of gauges that will be used on the CHSTP tracks. Using such a height would unnecessarily increase the pantograph sway and therefore gauge and put too much constraint on the design under tunnel or other structures.

In addition to the dynamic envelope that is to be used at overhead line support locations, the infrastructure design shall take account of the space necessary for installation of the contact line itself and the associated necessary electrical clearances. The space depends on the design of individual contact line and the combination of the different overhead contact systems used by the German, the Japanese and the French has been considered in the CHSTP design.

- In open route, for sections of the CHSTP dedicated to very high speed, the CHSTP space required for the live 25kV catenary between two supports takes into account the required electrical clearance for high speed 25kV live OCS conductors, installation dimensions and construction tolerances, and an OCS standard system height of 5'-3"(1600mm) corresponding to the maximum of standard system heights used for the German ICE high speed OCS 5'-3"(1600mm), Japanese Shinkansen High speed OCS 4'-11"(1500mm) and French TGV High OCS 4'-7.1"(1400mm)).

In open route, using a passing electrical clearance of 8.7"(220mm) in accordance with UIC electrical clearances and as recommended for very high speed, this resulting CHSTP overall electrical clearance required for the pantograph and the Overhead Contact System between two supports and for sections of the CHSTP that are dedicated to high-speed trains is, in alignment and for a contact wire height of 17'-4.7"(5300 mm), as shown in the figure below and refer to appendix for dimension detail:



**Figure 3.9 SPACE NECESSARY FOR 25KV OVERHEAD CONTACT SYSTEM FOR CHSTP SECTIONS
DEDICATED TO HIGH SPEED FOR A CONTACT WIRE HEIGHT OF 17'-4.7" (5300 mm)
IN OPEN ROUTE ALIGNMENT BETWEEN 2 SUPPORTS**

Notes: The height of 24'-4.6"(7433mm) is made of 17'-4.7"(5300 mm) for the contact wire height for CHSTP high speed dedicated sections + 5'-3"(1600mm) for the system height (worst case standard system height as used by the Germans for high speed) + 1'-0.6"(320mm) for the static electrical clearance (in accordance with UIC electrical clearances and as recommended for very high speed) + 5.9"(150mm) of uplift and hardware dimension + 2.5"(63mm) of track and OCS tolerances.

The lateral dimension of 2'-0.4"(620mm) is made of 1'-3.7"(400mm) for the maximum deflection of the contact wire under dynamic situation as recommended by the TSI standard for high speed lines + 8.7"(220mm) for the passing electrical clearance in accordance with UIC electrical clearances and as recommended for very high speed.

- Similarly in open route and for curved superelevated track, this resulting CHSTP overall electrical clearance required for the pantograph and for the live 25kV catenary between two supports and for sections of the CHSTP that are dedicated to high-speed trains is, for a contact wire height of 17'-4.7"(5300mm), as shown in the figure below:

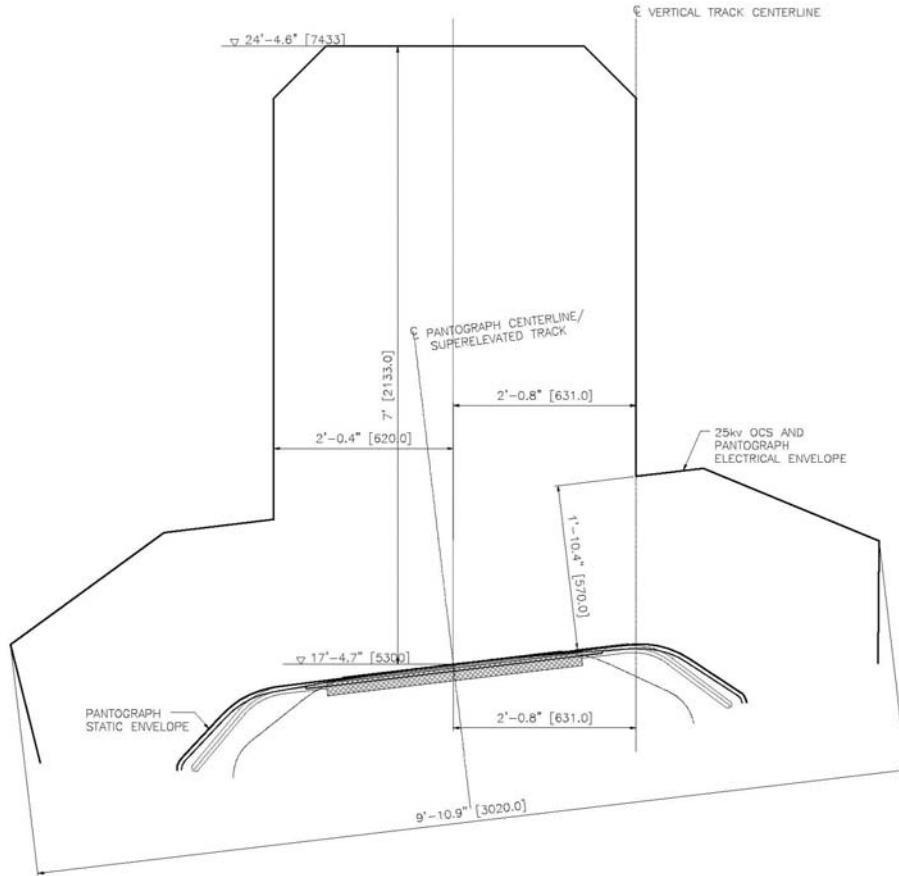


Figure 3.10 SPACE NECESSARY FOR 25KV OVERHEAD CONTACT SYSTEM FOR CHSTP SECTIONS DEDICATED TO HIGH SPEED FOR A CONTACT WIRE HEIGHT OF 17'-4.7"(5300mm) IN OPEN ROUTE BETWEEN 2 SUPPORTS FOR SUPERELEVATED TRACK

Notes: The height of 24'-4.6"(7433mm) is the same than previously determined for very high speed dedicated sections and for open route alignment and standard system height.

The lateral dimension of 2'-0.8"(631mm) compared to the 2'-0.4"(620mm) is due to the effect at the contact wire height of 17'-4.7"(5300mm), of the superelevation (7.1"(180mm) maximum for sections dedicated to high speed) as 2'-0.8"(631mm = 5300mm x 180mm / 1511mm).

- In tunnels and under structures, for sections of the CHSTP dedicated to very high speed, the CHSTP vertical space can be reduced using an OCS reduced system height of 3'-7.3"(1100mm) (minimum system height used for the German ICE high speed OCS 3'-7.3"(1100mm), Japanese Shinkansen High speed OCS 3'-7.3"(1100mm) and French TGV High OCS 2'-7.5"(800mm)). It is however taking into account the required electrical clearance for high speed 25kV live OCS and additional dimensions required for fixing parts and construction tolerance.
- In tunnels and under structures, this resulting CHSTP overall electrical clearance required for the pantograph and for the live 25kV catenary between two supports and for sections of the CHSTP that are dedicated to high-speed trains is, in alignment and for a contact wire height of 17'-4.7"(5300mm), as shown in the figure below:

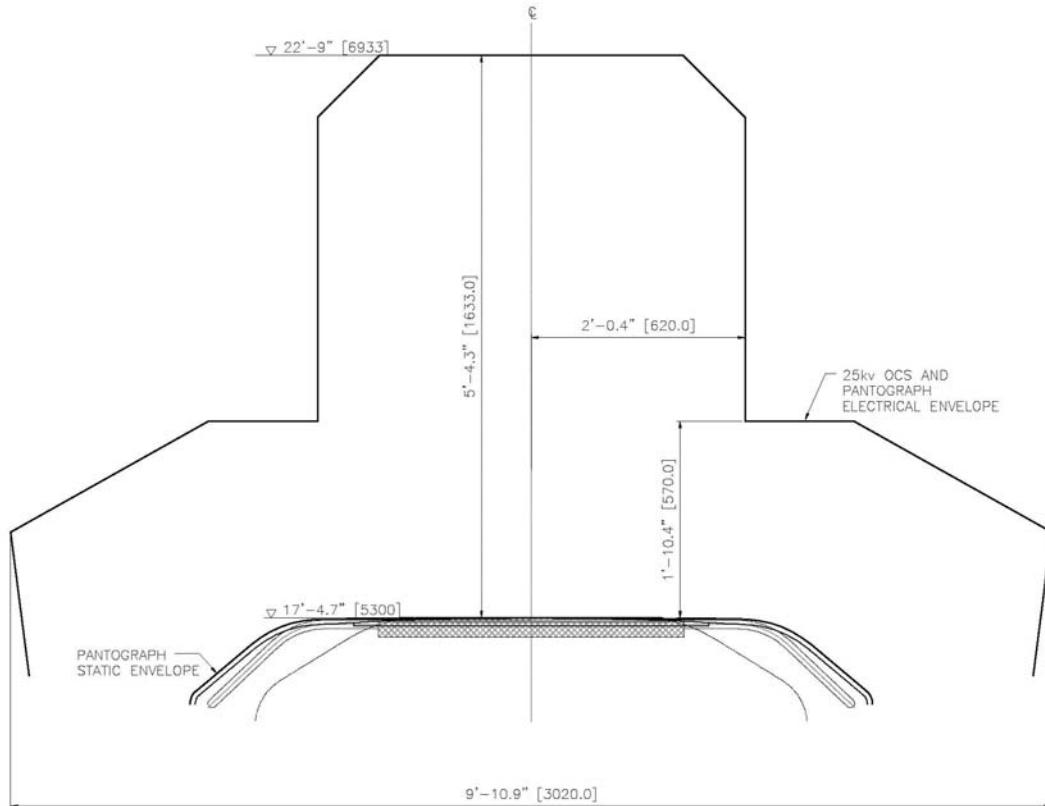


Figure 3.11 SPACE NECESSARY FOR 25KV OVERHEAD CONTACT SYSTEM FOR CHSTP SECTIONS DEDICATED TO HIGH SPEED FOR A CONTACT WIRE HEIGHT OF 17'-4.7"(5300mm) IN TUNNEL OR UNDER STRUCTURE IN ALIGNMENT BETWEEN 2 SUPPORTS

Notes: The height of 22'-9"(6933mm) is made of 17'-4.7"(5300mm) for the contact wire height for CHSTP high speed dedicated sections + 3'-7.3"(1100mm) for the reduced system height (worst case reduced system height as used by the Germans for high speed) in tunnel or under a structure + 1'-0.6"(320mm) for the static electrical clearance (in accordance with UIC electrical clearances and as recommended for very high speed) + 5.9"(150mm) of uplift and hardware dimension + 2.5"(63mm) of track and OCS tolerances.

The lateral dimension of 2'-0.4"(620mm) is made of 1'-3.7"(400mm) for the maximum deflection of the contact wire under dynamic situation as recommended by the TSI standard for high speed lines + 8.7"(220mm) for the passing electrical clearance in accordance with UIC electrical clearances and as recommended for very high speed.

- Similarly in tunnels and under structures and for curved superelevated track, this resulting CHSTP overall electrical clearance required for the pantograph and for the live 25kV catenary between two supports and for sections of the CHSTP that are dedicated to high-speed trains is, for a contact wire height of 17'-4.7"(5300mm), as shown in the figure below:

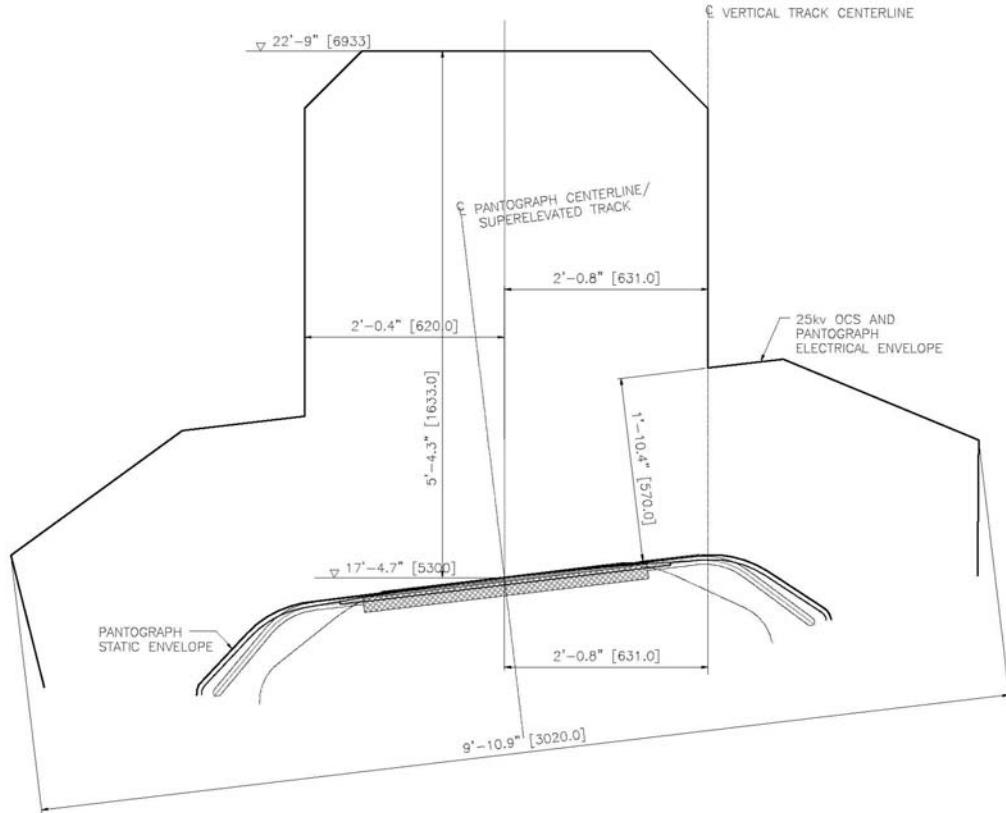


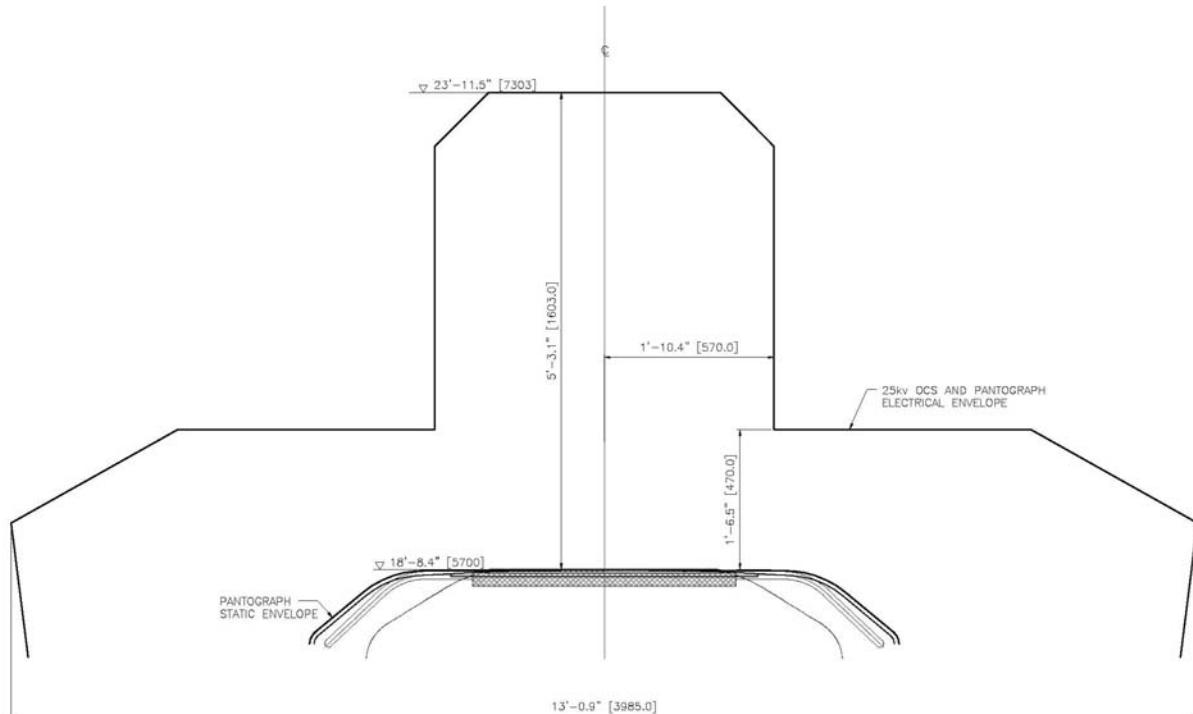
Figure 3.12 SPACE NECESSARY FOR 25KV OVERHEAD CONTACT SYSTEM FOR CHSTP SECTIONS DEDICATED TO HIGH SPEED FOR A CONTACT WIRE HEIGHT OF 17'-4.7"(5300mm) IN TUNNEL OR UNDER STRUCTURE BETWEEN 2 SUPPORTS FOR SUPERELEVATED TRACK

Notes: The height of 22'-9"(6933mm) is the same than previously determined for very high speed dedicated sections and for open route alignment and reduced system height in tunnel or under a structure.

The lateral dimension of 2'-0.8"(631mm) compared to the 2'-0.4"(620mm) is due to the effect at the contact wire height of 17'-4.7"(5300mm), of the superelevation (7.1"(180mm) maximum for sections dedicated to high speed) as 2'-0.8"(631mm = 5300mm x 180mm / 1511mm).

- In open route, for sections of the CHSTP that are shared use corridors for both high-speed trains and conventional passenger trains, the CHSTP space that would be required for the live 25kV catenary between two supports takes into account the required 25kV electrical clearance, installation dimensions and construction tolerances, and an OCS system height of 4'-0"(1220mm) for a 125mph(201Km/h) speed 25kV OCS (3'-7.3"(1100mm) system height used by the Germans, 3'-7.3"(1100mm) system height used by the Japanese and 3'-11.2"(1200mm) system height used by the French).

In open route, this resulting CHSTP overall electrical clearance required for the pantograph and the Overhead Contact System between two supports and for sections of the CHSTP that are shared use corridors for both high-speed trains and conventional passenger trains is, in alignment and for a contact wire height of 18'-8.4"(5700 mm), as shown in the figure below and refer to appendix for dimension detail:

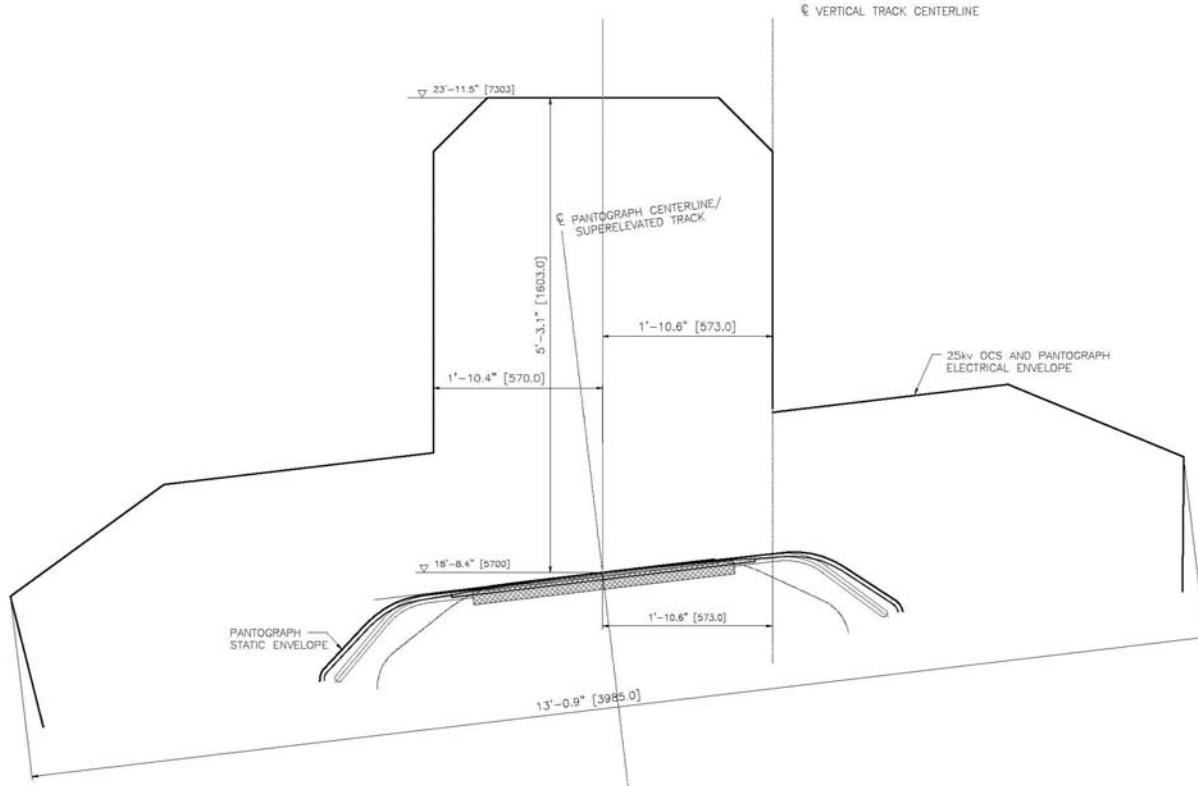


**Figure 3.13 SPACE NECESSARY FOR 25KV OVERHEAD CONTACT SYSTEM
FOR CHSTP SHARED USE CORRIDORS FOR A CONTACT WIRE HEIGHT OF 18'-8.4"(5700 mm)
IN OPEN ROUTE ALIGNMENT BETWEEN 2 SUPPORTS**

Notes: The height of 23'-11.5"(7303mm) is made of 18'-8.4"(5700 mm) for the contact wire height for CHSTP shared use corridors + 4'-0"(1220mm) for the system height (for a 125mph(201Km/h) speed 25kV OCS) including hardware dimension + 10.6"(270mm) for the static electrical clearance (normal static electrical clearance in accordance with UIC electrical clearances) + 2"(50mm) of uplift + 2.5"(63mm) of track and OCS tolerances.

The lateral dimension of 1'-10.4"(570mm) is made of 1'-3.7"(400mm) for the maximum deflection of the contact wire under dynamic situation + 6.7"(170mm) for the passing electrical clearance (normal passing electrical clearance in accordance with UIC electrical clearances).

- Similarly in open route and for curved superelevated track, this resulting CHSTP overall electrical clearance required for the pantograph and for the live 25kV catenary between two supports and for sections of the CHSTP that are shared use corridors for both high-speed trains and conventional passenger trains is, for a contact wire height of 18'-8.4"(5700 mm), as shown in the figure below:



**Figure 3.14 SPACE NECESSARY FOR 25KV OVERHEAD CONTACT SYSTEM
FOR CHSTP SHARED USE CORRIDORS FOR A CONTACT WIRE HEIGHT OF 18'-8.4"(5700 mm)
IN OPEN ROUTE BETWEEN 2 SUPPORTS FOR SUPERELEVATED TRACK**

Notes: The height of 23'-11.5"(7303mm) is the same than previously determined for shared use corridors and for open route alignment and standard system height for a 125mph(201Km/h) speed 25kV OCS.

The lateral dimension of 1'-10.6"(573mm) compared to the 1'-10.4"(570mm) is due to the effect at the contact wire height of 18'-8.4"(5700mm), of the superelevation (where an exceptional value of 6"(152mm) is being used for calculation in case there is a radius less than 6,500ft(1981m) for a speed of 125mph(201Km/h) in a shared use corridor) as 1'-10.6"(573mm = 5700mm x 152mm / 1511mm).

- In tunnel and under a structure, for sections of the CHSTP that are shared use corridors for both high-speed trains and conventional passenger trains, the CHSTP vertical space for a 125mph(201Km/h) speed 25kV OCS can be reduced using an OCS reduced system height of 3'-3.4"(1000mm). It is however taking into account the required electrical clearance for 25kV live OCS and additional dimensions required for fixing parts and construction tolerance.

In tunnels and under structures, this resulting CHSTP overall electrical clearance required for the pantograph and for the live 25kV catenary between two supports and for sections of the CHSTP that are shared use corridors for both high-speed trains and conventional passenger trains is, in alignment and for a contact wire height of 18'-8.4"(5700 mm), as shown in the figure below:

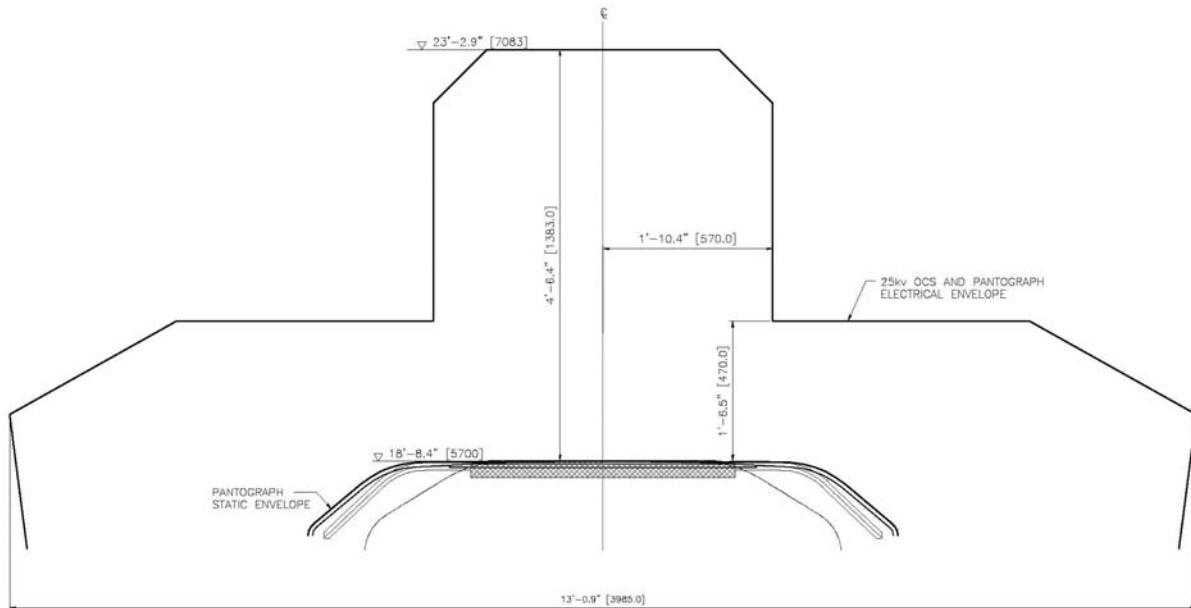


Figure 3.15 SPACE NECESSARY FOR 25KV OVERHEAD CONTACT SYSTEM FOR CHSTP SHARED USE CORRIDORS FOR A 18'-8.4"(5700 mm) CONTACT WIRE HEIGHT IN TUNNEL OR UNDER STRUCTURE IN ALIGNMENT BETWEEN 2 SUPPORTS

Notes: The height of 23'-2.9"(7083mm) is made of 18'-8.4"(5700 mm) for the contact wire height for CHSTP shared use corridors + 3'-3.4"(1000mm) including hardware dimension for the reduced system height in tunnel or under a structure + 10.6"(270mm) for the static electrical clearance (normal static electrical clearance in accordance with UIC electrical clearances) + 2"(50mm) of uplift + 2.5"(63mm) of track and OCS tolerances.

The lateral dimension of 1'-10.4"(570mm) is made of 1'-3.7"(400mm) for the maximum deflection of the contact wire under dynamic situation + 6.7"(170mm) for the passing electrical clearance (normal passing electrical clearance in accordance with UIC electrical clearances).

- Similarly in tunnels and under structures and for curved superelevated track, this resulting CHSTP overall electrical clearance required for the pantograph and the for the live 25kV catenary between two supports and for sections of the CHSTP that are shared use corridors for both high-speed trains and conventional passenger trains is, for a contact wire height of 18'-8.4"(5700 mm), as shown in the figure below:

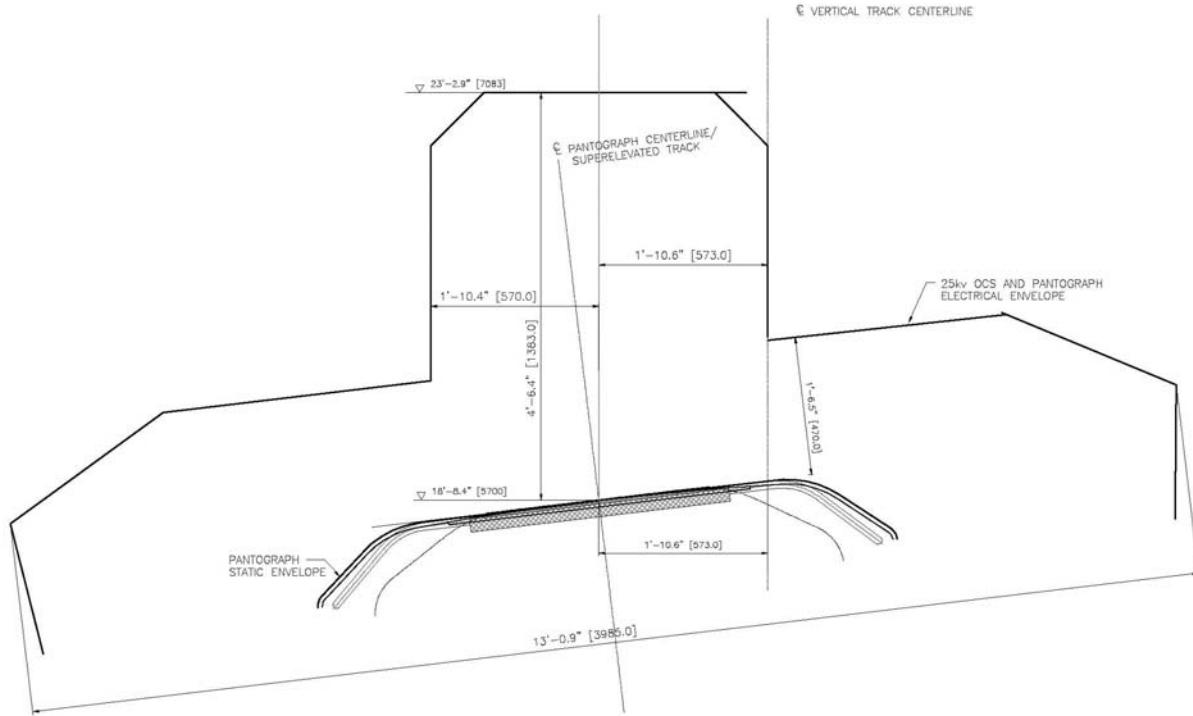


Figure 3.16 SPACE NECESSARY FOR 25KV OVERHEAD CONTACT SYSTEM FOR CHSTP SHARED USE CORRIDORS FOR A 18'-8.4"(5700 mm) CONTACT WIRE HEIGHT IN TUNNEL OR UNDER STRUCTURE BETWEEN 2 SUPPORTS FOR SUPERELEVATED TRACK

Notes: The height of 23'-2.9"(7083mm) is the same than previously determined for shared use corridors for a reduced system height of 3'-3.4"(1000mm) in tunnel or under a structure for a 125mph(201Km/h) speed 25kV OCS.

The lateral dimension of 1'-10.6"(573mm) compared to the 1'-10.4"(570mm) is due to the effect at the contact wire height of 18'-8.4"(5700mm), of the superelevation (where an exceptional value of 6"(152mm) is being used for calculation in case there is a radius less than 6,500ft(1981m) for a speed of 125mph(201Km/h) in a shared use corridor) as 1'-10.6"(573mm = 5700mm x 180mm / 1511mm).

4.0 SUMMARY AND RECOMMENDATIONS

The recommended criteria for the Pantograph clearance envelopes and for the space required for the Overhead Contact System for the CHSTP is presented below.

4.1 PANTOGRAPH ENVELOPES SPACE REQUIRED FOR THE OVERHEAD CONTACT SYSTEM BETWEEN TWO SUPPORTS

Combined static pantograph envelope

For the purpose of defining a combined static pantograph envelope for the California High Speed Train Project, the design will consider the guideline recommendation of Chapter 33 of the AREMA Manual which assumes a pantograph dimension of 6'-6"(1980mm) over the tips of the horn. This dimension is exceeding by 1.2"(30mm) the widest of the European standard profile for high speed, Japanese and widest German pantograph profiles that is the 6'-4.8"(1950mm) German pantograph profile.

The resulting pantograph combined static gauge to be used for the CHSTP is consequently as shown below:

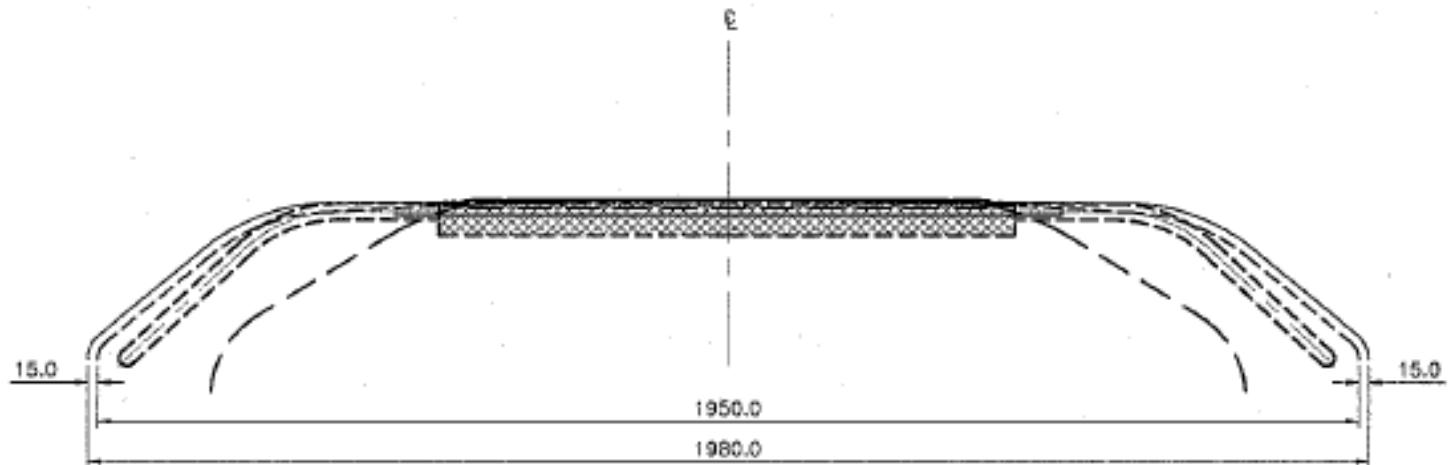


Figure 4.1 CHSTP COMBINED STATIC PANTOGRAPH GAUGE

Combined dynamic pantograph envelopes

Also, for the purpose of defining a combined dynamic pantograph envelopes for the California High Speed Train Project, the design will consider:

- For sections of the CHSTP dedicated to high speed, a contact wire of 17'-4.7" (5300 mm) above top of rail (as used by the Germans on their Cologne-Rhine Main high speed line), resulting in the space necessary for the dynamic passage of pantographs for the sections of the CHSTP dedicated to very high speed (with a dynamic pantograph width of 8'-5.6"(2580mm) and an uplift value of and $S = 9.8"(250mm)$) as shown below:

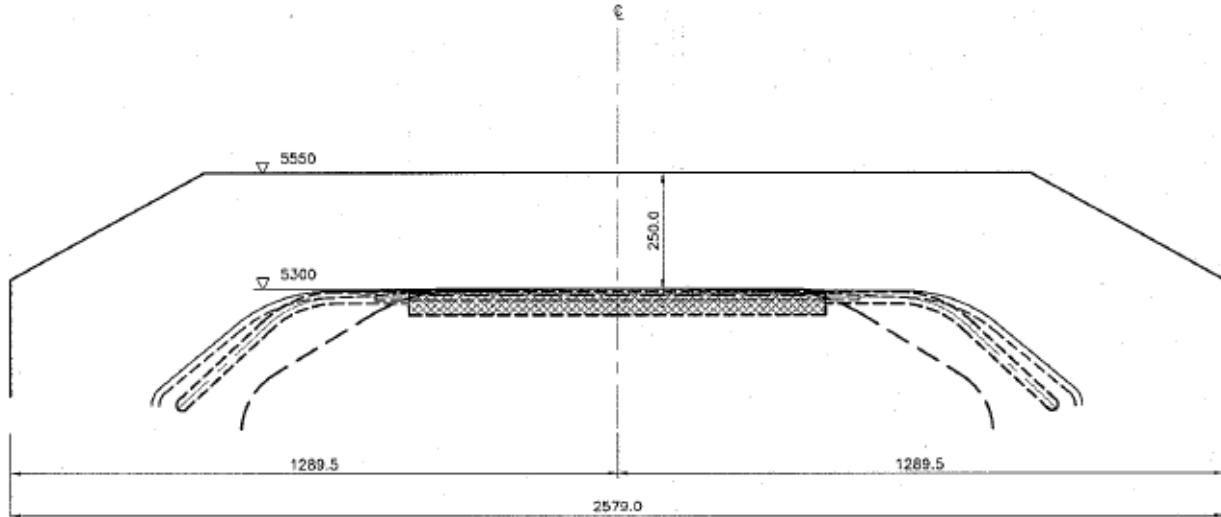


Figure 4.2 DYNAMIC ENVELOPE OF PANTOGRAPH FOR CHSTP SECTIONS DEDICATED TO HIGH SPEED FOR CONTACT WIRE HEIGHT OF 17'-4.7"(5300mm)

- For sections of the CHSTP that are shared use corridors for both high-speed trains and conventional passenger trains, a contact wire of 18'-8.4"(5700 mm) resulting in the space necessary for the dynamic passage of pantographs (with a dynamic pantograph width of 11'-7.6"(3545mm) and an uplift value of $S = 7.9"(200mm)$) as shown below:

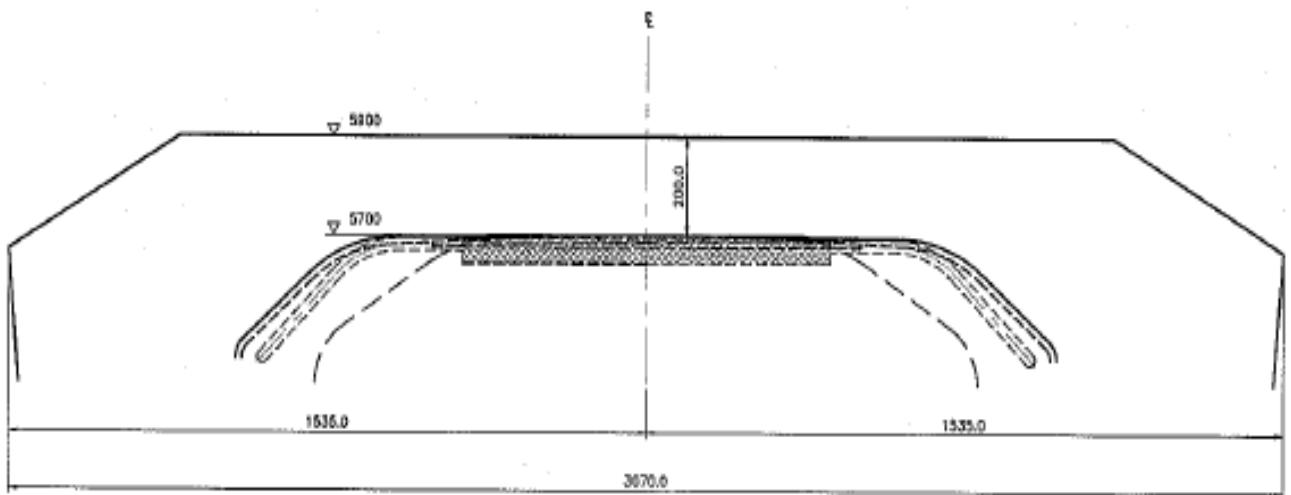


Figure 4.3 DYNAMIC ENVELOPE OF PANTOGRAPH FOR CHSTP SHARED USE CORRIDORS FOR CONTACT WIRE HEIGHT OF 18'-8.4"(5700 mm)

4.2 ELECTRICAL ENVELOPE OR SPACE REQUIRED FOR THE CATENARY BETWEEN TWO SUPPORTS

Also, for the purpose of defining, for the California High Speed Train Project, the electrical envelope or space required for the pantograph and for the live 25kV catenary between two supports (but excluding the space required for the associated negative longitudinal feeder), the design will consider the following different situations: For both sections of the CHSTP dedicated to very high speed and for sections of the CHSTP that are shared used corridors, in open route as well as in a tunnel or under a structure.

These envelopes are shown below:

<p>In open route, for a contact wire height of 17'-4.7" (5300mm), in alignment and for sections of the CHSTP dedicated to very high speed:</p>	<p>In open route, for a contact wire height of 17'-4.7" (5300mm), in superelevated curved track and for sections of the CHSTP dedicated to very high speed:</p>

Figure 4.4 SPACE NECESSARY FOR 25KV OVERHEAD CONTACT SYSTEM FOR CHSTP SECTIONS DEDICATED TO HIGH SPEED FOR A CONTACT WIRE HEIGHT OF 17'-4.7" (5300mm) IN OPEN ROUTE ALIGNMENT BETWEEN 2 SUPPORTS

Figure 4.5 SPACE NECESSARY FOR 25KV OVERHEAD CONTACT SYSTEM FOR CHSTP SECTIONS DEDICATED TO HIGH SPEED FOR A CONTACT WIRE HEIGHT OF 17'-4.7" (5300mm) IN OPEN ROUTE BETWEEN 2 SUPPORTS FOR SUPERELEVATED TRACK

<p>In a tunnel or under a structure, for a contact wire height of 17'-4.7"(5300mm), in alignment and for sections of the CHSTP dedicated to very high speed:</p>	<p>In a tunnel or under a structure, for a contact wire height of 17'-4.7"(5300mm), in alignment and for sections of the CHSTP dedicated to very high speed:</p>

Figure 4.6 SPACE NECESSARY FOR 25KV OVERHEAD CONTACT SYSTEM FOR CHSTP SECTIONS DEDICATED TO HIGH SPEED FOR A CONTACT WIRE HEIGHT OF 17'-4.7"(5300mm) IN TUNNEL OR UNDER STRUCTURE IN ALIGNMENT BETWEEN 2 SUPPORTS

Figure 4.7 SPACE NECESSARY FOR 25KV OVERHEAD CONTACT SYSTEM FOR CHSTP SECTIONS DEDICATED TO HIGH SPEED FOR A CONTACT WIRE HEIGHT OF 17'-4.7"(5300mm) IN TUNNEL OR UNDER STRUCTURE BETWEEN 2 SUPPORTS FOR SUPELEVATED TRACK

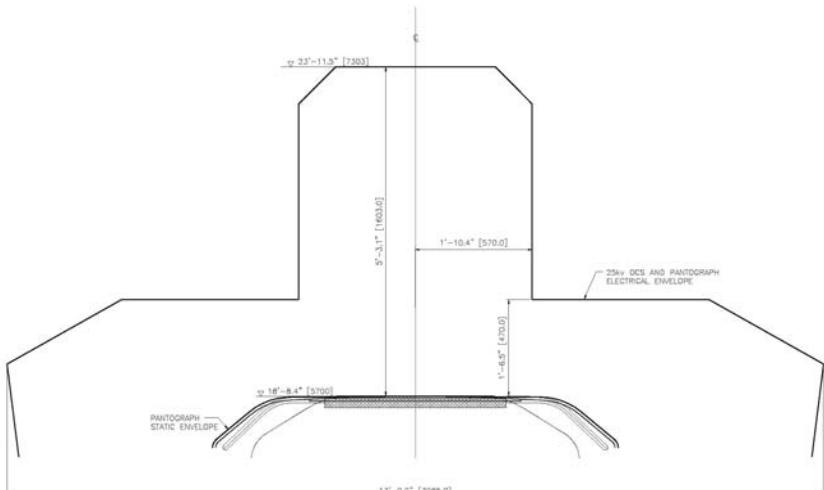
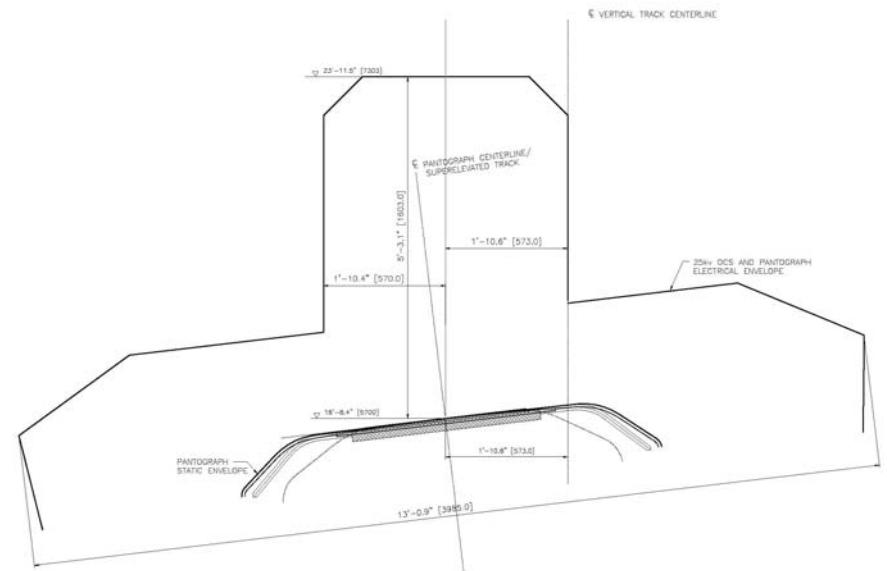
<p>In open route, for a contact wire height of 18'-8.4"(5700 mm), in alignment and for sections of the CHSTP that are shared use corridors for both high-speed trains and conventional passenger trains:</p>	<p>In open route, for a contact wire height of 18'-8.4"(5700 mm), in superelevated curved track and for sections of the CHSTP that are shared use corridors for both high-speed trains and conventional passenger trains:</p>
	

Figure 4.8 SPACE NECESSARY FOR 25KV OVERHEAD CONTACT SYSTEM FOR CHSTP SHARED USE CORRIDORS FOR A CONTACT WIRE HEIGHT OF 18'-8.4"(5700 mm) IN OPEN ROUTE ALIGNMENT BETWEEN 2 SUPPORTS

Figure 4.9 SPACE NECESSARY FOR 25KV OVERHEAD CONTACT SYSTEM FOR CHSTP SHARED USE CORRIDORS FOR A CONTACT WIRE HEIGHT OF 18'-8.4"(5700 mm) IN OPEN ROUTE BETWEEN 2 SUPPORTS FOR SUPERELEVATED TRACK

<p>In a tunnel or under a structure, for a contact wire height of 18'-8.4"(5700 mm), in alignment and for sections of the CHSTP that are shared use corridors for both high-speed trains and conventional passenger trains:</p>	<p>In a tunnel or under a structure, for a contact wire height of 18'-8.4"(5700 mm), in superelevated curved track and for sections of the CHSTP that are shared use corridors for both high-speed trains and conventional passenger trains:</p>

Figure 4.10 SPACE NECESSARY FOR 25KV OVERHEAD CONTACT SYSTEM FOR CHSTP SHARED USE CORRIDORS FOR A 18'-8.4"(5700 mm) CONTACT WIRE HEIGHT IN TUNNEL OR UNDER STRUCTURE IN ALIGNMENT BETWEEN 2 SUPPORTS

Figure 4.11 SPACE NECESSARY FOR 25KV OVERHEAD CONTACT SYSTEM FOR CHSTP SHARED USE CORRIDORS FOR A 18'-8.4"(5700 mm) CONTACT WIRE HEIGHT IN TUNNEL OR UNDER STRUCTURE BETWEEN 2 SUPPORTS FOR SUPERELEVATED TRACK

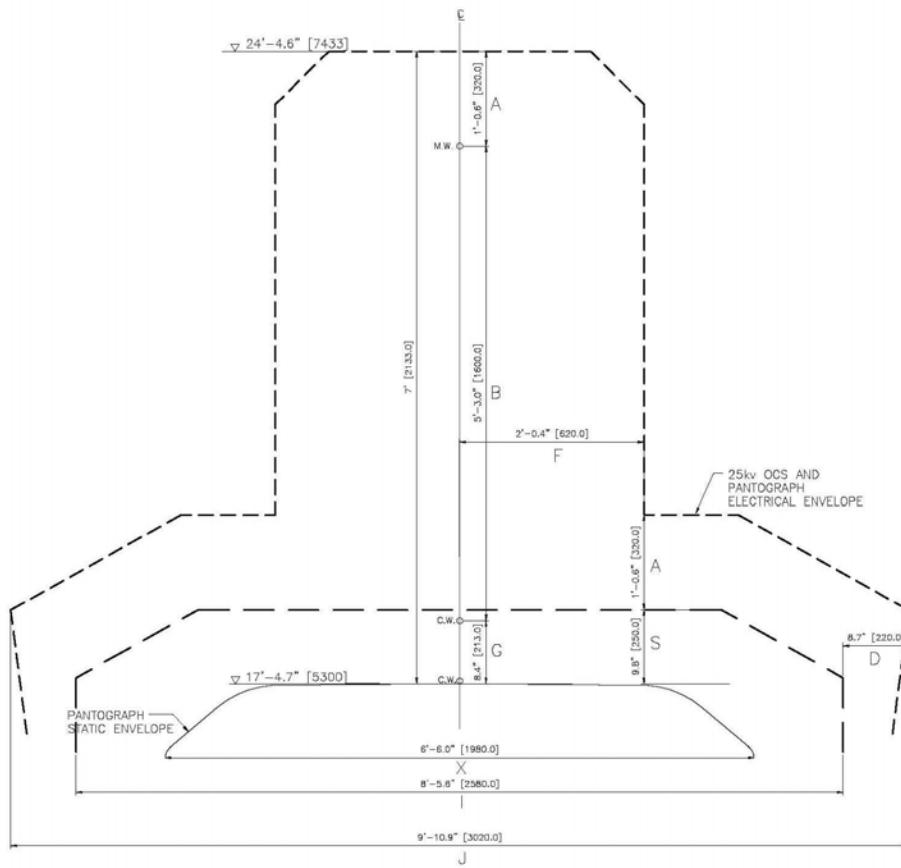
5.0 SOURCE INFORMATION AND REFERENCES

- The Manual for Railway Engineering of the American Railway Engineering and Maintenance of Way Association (AREMA Manual)
- California Public Utilities Commission General Order 26-D
- CHSTP Basis of Design Policy – California High Speed Rail Program – Jan 08
- Technical Memorandum TM 1.1.10 Structure Gauge
- Amtrak guidelines and present practices
- Technical Specifications for Interoperability (TSI) of European High Speed lines
- UIC standards

6.0 DESIGN MANUAL CRITERIA

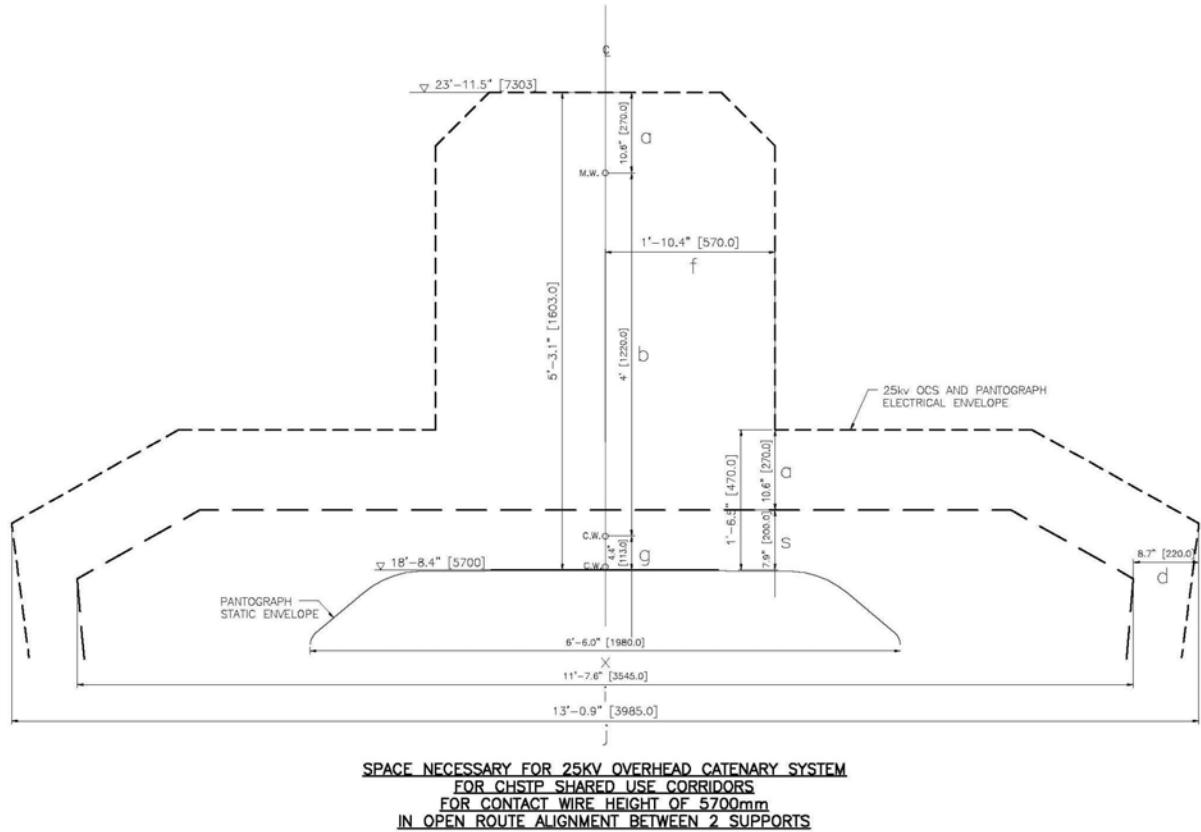
<p>The dimensions data (rounded to the next 10mm) that are to be included in the Design Manual are:</p> <p><u>For the contact wire height:</u></p> <ul style="list-style-type: none"> - for CHSTP sections dedicated to high speed only - for CHSTP sections that are shared use corridors <p><u>For the pantograph:</u></p> <ul style="list-style-type: none"> - a pantograph static dimension over the tips of the horn (as per the guideline recommendation of Chapter 33 of the AREMA Manual) - for <u>CHSTP sections dedicated to high speed only</u>, a pantograph dynamic envelope to be used for design at support locations (with a <u>contact wire height of 5300mm above top of rail</u>) - for <u>CHSTP sections that are shared use corridors</u>, a pantograph dynamic envelope to be used for design at support locations (with a <u>contact wire height of 5700mm above top of rail</u>) <p><u>For the pantograph and 25kV live catenary space envelope (between 2 supports):</u></p> <ul style="list-style-type: none"> - for <u>CHSTP sections dedicated to high speed only</u> (with a <u>contact wire height of 5300mm above top of rail</u>), pantograph and catenary (excluding its associated negative feeder) electrical envelopes (to be used between two supports) of 		
<p>in alignment in open route</p>		17'-4.7" 18'-8.4"
<p>in curved superelevated track in open route</p>		6'-6"
<p>in alignment in tunnel</p>		8'-5.6" wide and a height of 18'-2.5" that includes uplift
<p>in curved superelevated track in tunnel</p>		11'-7.6" wide and a height of 19'-4.3" that includes uplift
<p>- for <u>CHSTP sections that are shared use corridors</u> (with a <u>contact wire height of 5700mm above top of rail</u>), pantograph and catenary (excluding its associated negative feeder) electrical envelopes (to be used between two supports) of</p>		
<p>in alignment in open route</p>		9'-10.9" x 1'-10.4" + 7'-0" x 4'-0.8"
<p>in curved superelevated track in open route</p>		9'-10.9" x 1'-10.4" + 7'-0" x 4'-1.2"
<p>in alignment in tunnel</p>		9'-10.9" x 1'-10.4" + 5'-4.3" x 4'-0.8"
<p>in curved superelevated track in tunnel</p>		9'-10.9" x 1'-10.4" + 5'-4.3" x 4'-1.2"
<p>- for <u>CHSTP sections that are shared use corridors</u> (with a <u>contact wire height of 5700mm above top of rail</u>), pantograph and catenary (excluding its associated negative feeder) electrical envelopes (to be used between two supports) of</p>		
<p>in alignment in open route</p>		13'-0.9" x 1'-6.5" + 5'-3.1" x 3'-8.9"
<p>in curved superelevated track in open route</p>		13'-0.9" x 1'-6.5" + 5'-3.1" x 3'-9.1"
<p>in alignment in tunnel</p>		13'-0.9" x 1'-6.5" + 4'-6.4" x 3'-8.9"
<p>in curved superelevated track in tunnel</p>		13'-0.9" x 1'-6.5" + 4'-6.4" x 3'-9.1"

APPENDIX

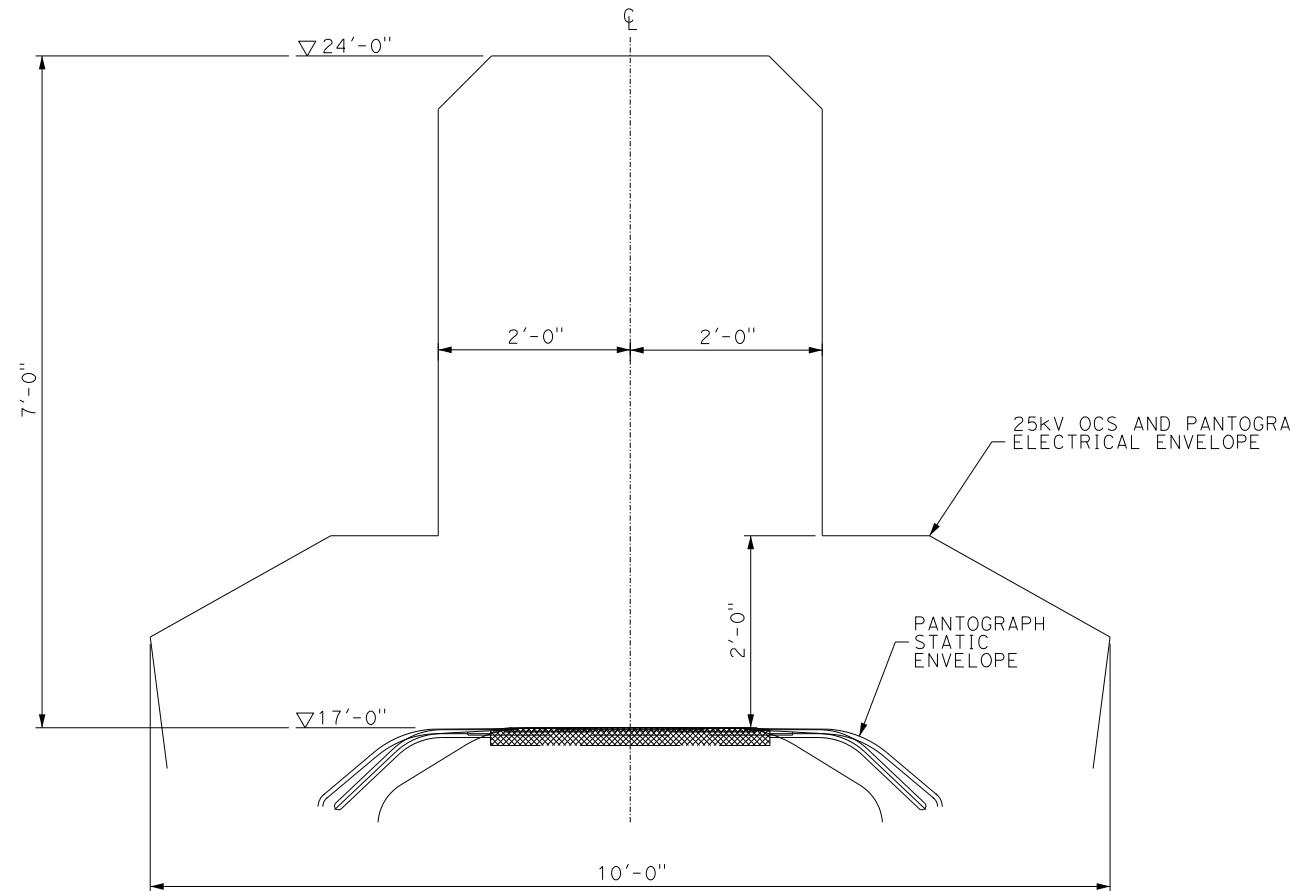


SPACE NECESSARY FOR 25KV OVERHEAD CATENARY SYSTEM
FOR CHSTP SECTIONS DEDICATED TO HIGH SPEED
FOR CONTACT WIRE HEIGHT OF 5300mm
IN OPEN ROUTE ALIGNMENT BETWEEN 2 SUPPORTS

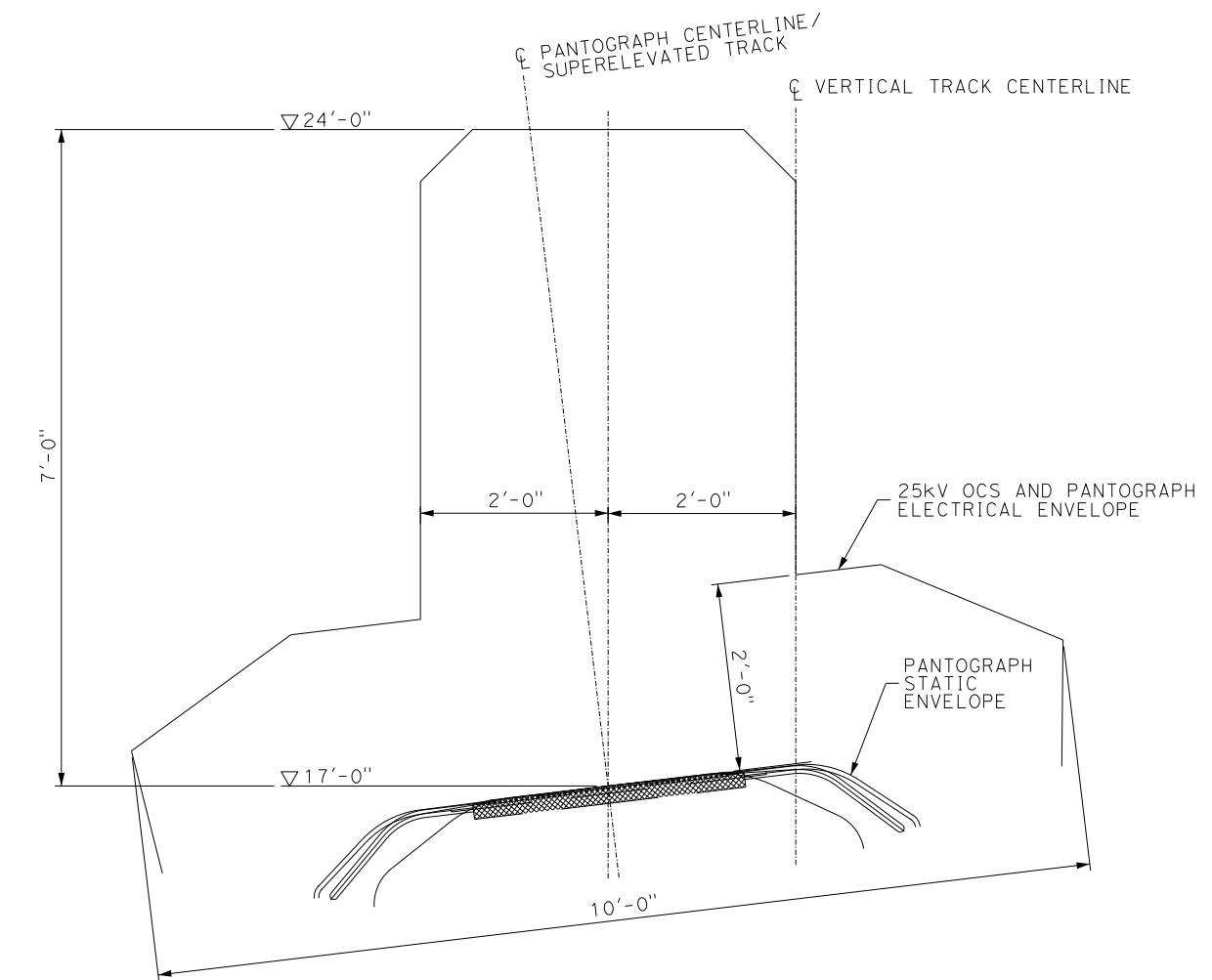
- A = Static electrical clearance per UIC-606
- D = Passing electrical clearance per UIC-606
- B = System depth dedicated to high speed (maximum system height of German ICE high speed OCS 5'-3"(1600mm), Japanese Shinkansen High speed OCS 4'-11"(1500mm) and French TGV High OCS 4'-7.1"(1400mm))
- F = Wire deflection (maximum deflection of the contact wire under dynamic situation as recommended by the TSI standard for high speed lines) + D (Passing Electrical Clearance per UIC-606)
- G = 5.9"(150mm) Wire uplift and hardware dimension + 2.5"(63mm) track and OCS tolerances
- X = CHSTP combined maximum pantograph static envelope (see figure 3.4)
- I = Total width of dynamic pantograph envelope per STI formula (= 2 x L2 see figure 3.5 and 3.7)
- J = Total width of electrical envelope (= I + 2 x D)
- S = Designed pantograph uplift for clearance purpose (see figure 3.5)



- a = Static electrical clearance per UIC-606
- d = Passing electrical clearance per UIC-606
- b = System depth (4'-0"(1220mm)) for shared use corridors and is slightly larger than the maximum system depth of Germans (3'-7.3"(1100mm), Japanese (3'-7.3"(1100mm)), and French (3'-11.2"(1200mm)))
- f = Wire deflection (maximum deflection of the contact wire under dynamic situation as recommended by the TSI standard for high speed lines) + d (Passing Electrical Clearance per UIC-606)
- g = 2"(50mm) of uplift + 2.5"(63mm) of track and OCS tolerances
- x = CHSTP combined maximum pantograph static envelope (see figure 3.4)
- i = Total width of dynamic pantograph envelope per AREMA chapter 33 formula (=2Ss+X+E+2L see figure 3.8)
- j = Total width of electrical envelope (= i + 2 x d)
- s = Designed pantograph uplift for clearance purpose (see figure 3.5)



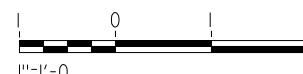
SPACE NECESSARY FOR 25kV OVERHEAD CONTACT SYSTEM
FOR CHSTP SECTIONS DEDICATED TO HIGH SPEED
FOR CONTACT WIRE HEIGHT OF 17'-0" IN OPEN ROUTE ALIGNMENT



SPACE NECESSARY FOR 25kV OVERHEAD CONTACT SYSTEM
FOR CHSTP SECTIONS DEDICATED TO HIGH SPEED
FOR CONTACT WIRE HEIGHT OF 17'-0" IN OPEN ROUTE ALIGNMENT FOR SUPERELEVATED TRACK

NOTE:

1. THE 25kV OCS ELECTRICAL ENVELOPE DOES NOT INCLUDE THE NECESSARY SPACE REQUIREMENT FOR THE 25kV NEGATIVE FEEDER WIRE IN PHASE OPPOSITION TO THE 25kV CONTACT WIRE.



REV	DATE	BY	CHK	APP

DESCRIPTION		DATE
		07/07-09

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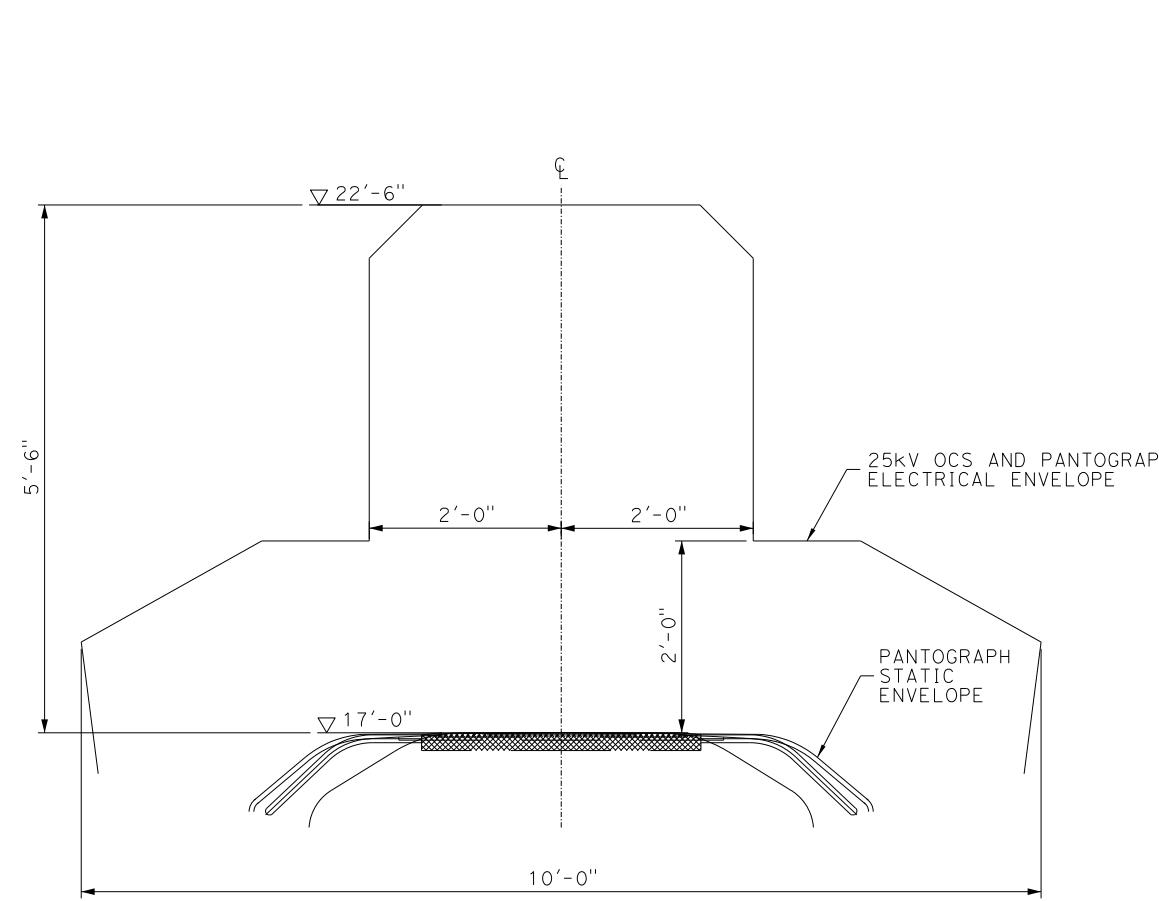


CALIFORNIA HIGH-SPEED RAIL AUTHORITY
FLY CALIFORNIA
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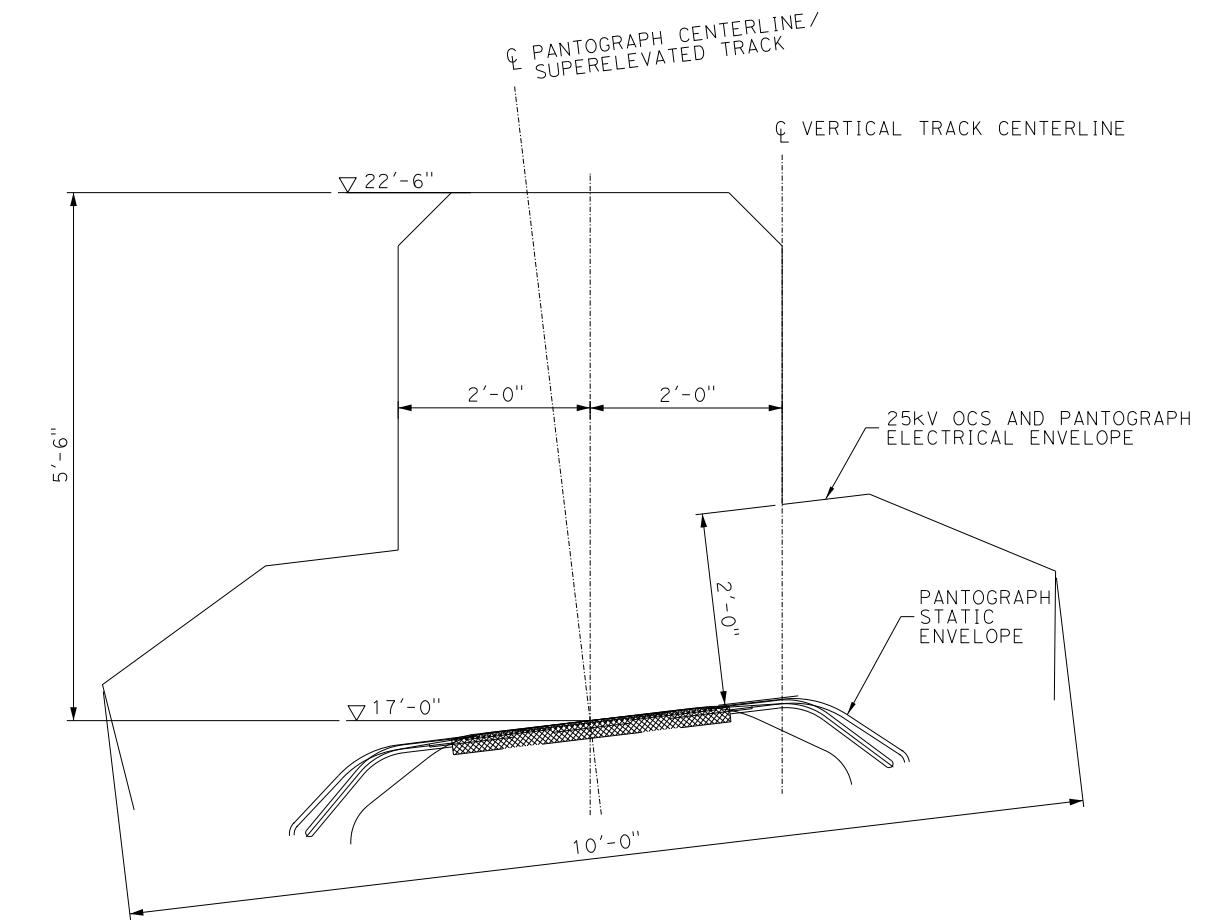
CALIFORNIA HIGH-SPEED TRAIN PROJECT

25kV OVERHEAD CONTACT SYSTEM AND
PANTOGRAPH CLEARANCE ENVELOPE
SHEET 1 OF 4

CONTRACT NO.	13259B
DRAWING NO.	TM 3.2.3-A
SCALE	1"=1'-0"
SHEET NO.	



SPACE NECESSARY FOR 25kV OVERHEAD CONTACT SYSTEM
FOR CHSTP SECTIONS DEDICATED TO HIGH SPEED
FOR CONTACT WIRE HEIGHT OF 17'-0"
ALIGNMENT IN TUNNEL OR STRUCTURE



SPACE NECESSARY FOR 25kV OVERHEAD CONTACT SYSTEM
FOR CHSTP SECTIONS DEDICATED TO HIGH SPEED
FOR CONTACT WIRE HEIGHT OF 17'-0"
IN TUNNEL OR STRUCTURE FOR SUPERELEVATED TRACK

NOTE:

1. THE 25kV OCS ELECTRICAL ENVELOPE DOES NOT INCLUDE THE NECESSARY SPACE REQUIREMENT FOR THE 25kV NEGATIVE FEEDER WIRE IN PHASE OPPOSITION TO THE 25kV CONTACT WIRE.

1"=1'-0" 0 1 2

REV	DATE	BY	CHK	APP	DESCRIPTION
					07-07-09

DESIGNED BY E. SCOTSON
DRAWN BY J. LAU
CHECKED BY A. MURPHY
IN CHARGE E. SCOTSON
DATE 07-07-09

**PARSONS
BRINCKERHOFF**

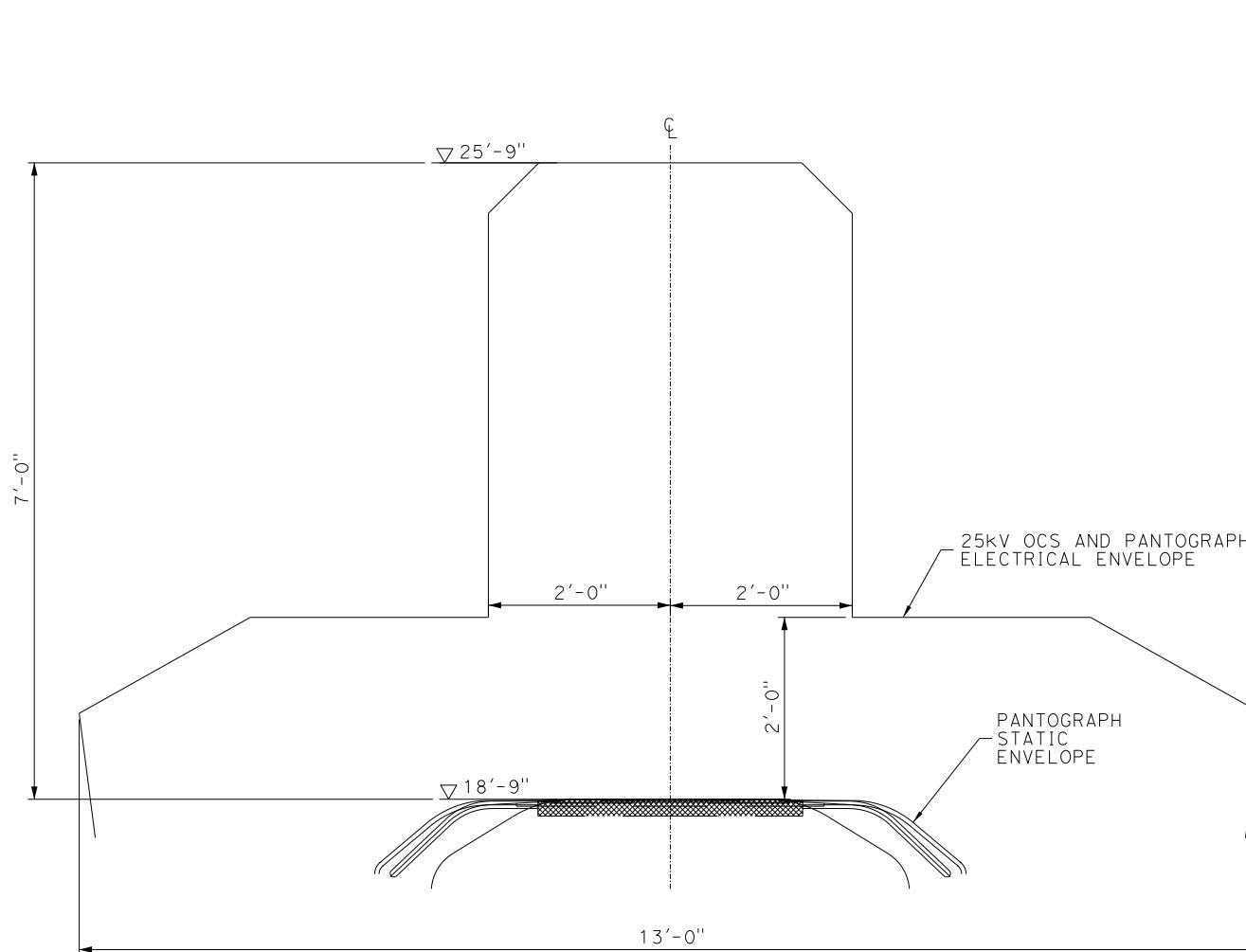


CALIFORNIA HIGH-SPEED RAIL AUTHORITY
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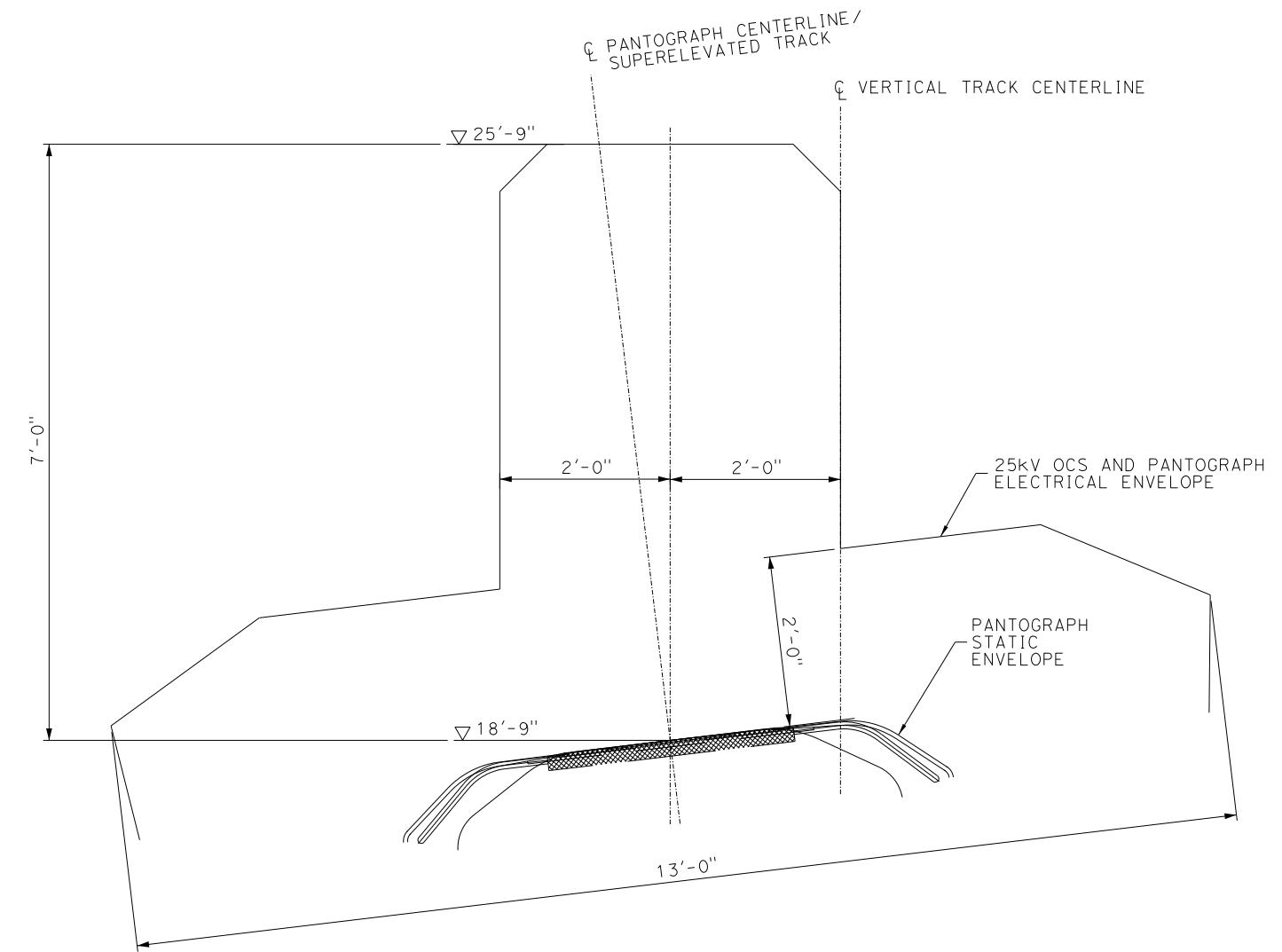
CALIFORNIA HIGH-SPEED TRAIN PROJECT

25kV OVERHEAD CONTACT SYSTEM AND
PANTOGRAPH CLEARANCE ENVELOPE
SHEET 2 OF 4

CONTRACT NO. 13259B
DRAWING NO. TM 3.2.3-B
SCALE 1"=1'-0"
SHEET NO.



SPACE NECESSARY FOR 25KV OVERHEAD CONTACT SYSTEM
FOR CHSTP SECTIONS DEDICATED TO HIGH SPEED
FOR CONTACT WIRE HEIGHT OF 18'-9" IN OPEN ROUTE ALIGNMENT



SPACE NECESSARY FOR 25KV OVERHEAD CONTACT SYSTEM
FOR CHSTP SECTIONS DEDICATED TO HIGH SPEED
FOR CONTACT WIRE HEIGHT OF 18'-9" IN OPEN ROUTE ALIGNMENT FOR SUPERELEVATED TRACK

NOTE:

1. THE 25KV OCS ELECTRICAL ENVELOPE DOES NOT INCLUDE THE NECESSARY SPACE REQUIREMENT FOR THE 25KV NEGATIVE FEEDER WIRE IN PHASE OPPOSITION TO THE 25KV CONTACT WIRE.

0
1'-0" 2

REV	DATE	BY	CHK	APP	DESCRIPTION
					07-07-09

DESIGNED BY E. SCOTSON
DRAWN BY J. LAU
CHECKED BY A. MURPHY
IN CHARGE E. SCOTSON
DATE 07-07-09

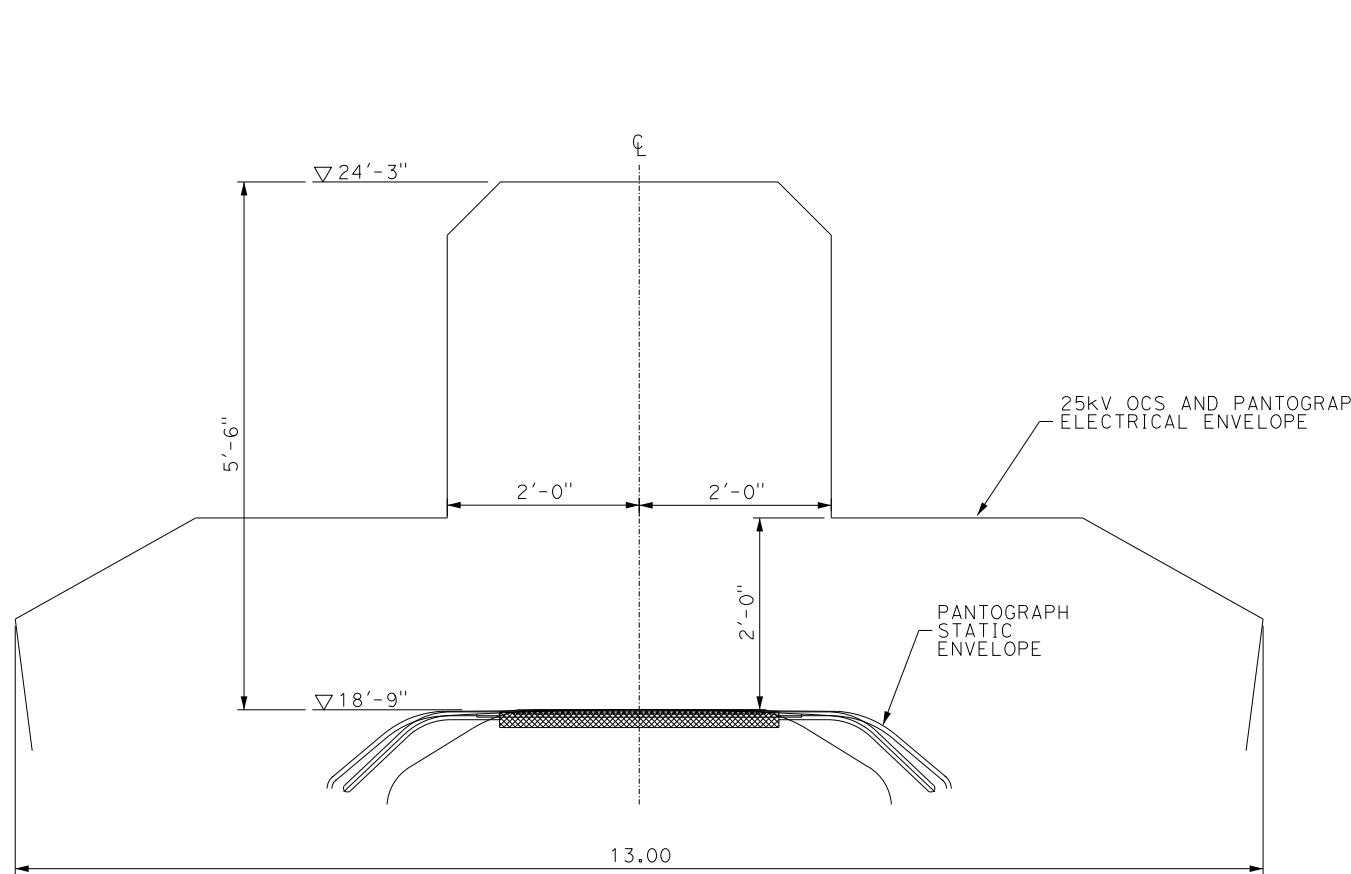
**PARSONS
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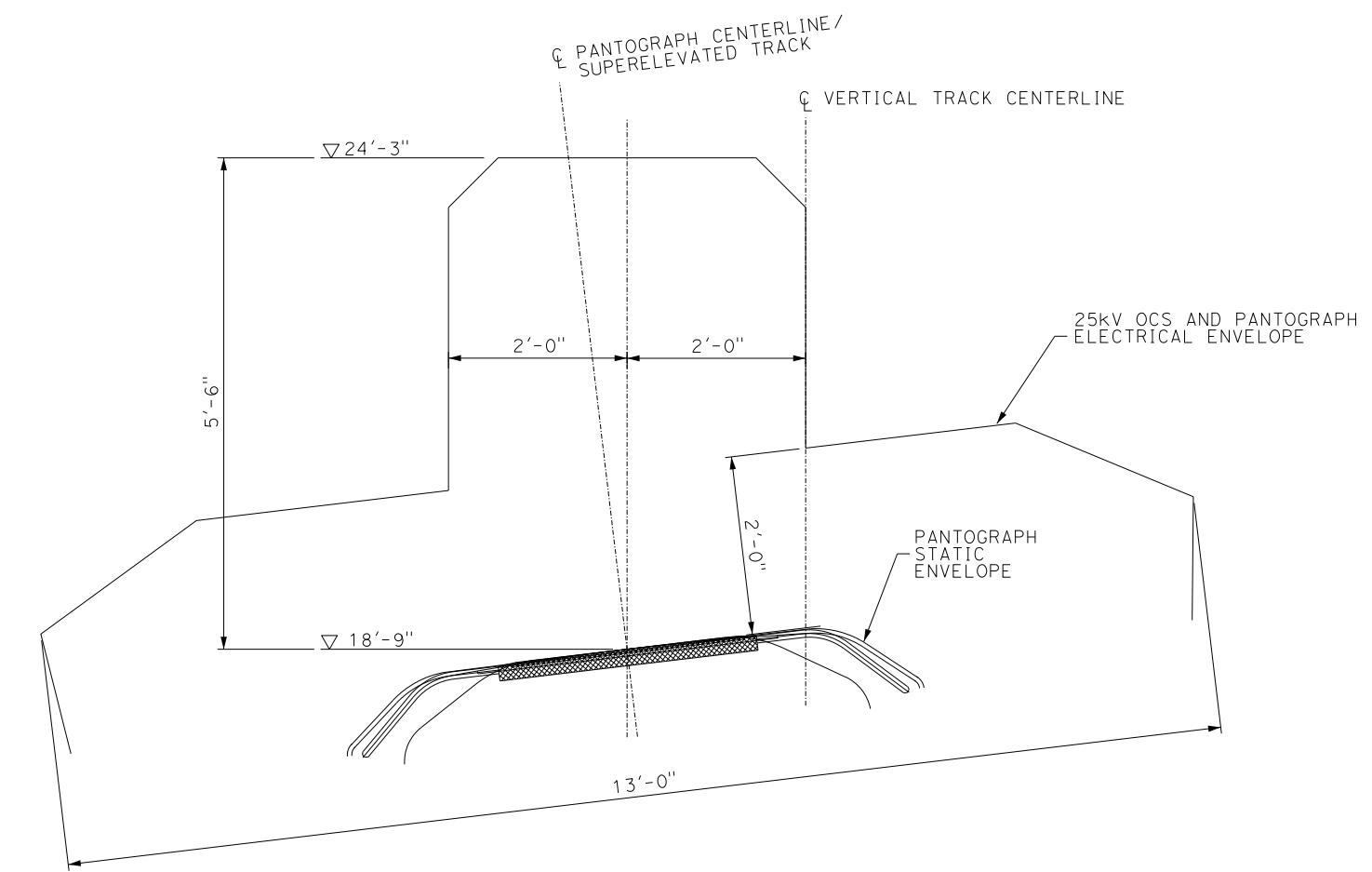
CALIFORNIA HIGH-SPEED TRAIN PROJECT

25KV OVERHEAD CONTACT SYSTEM AND
PANTOGRAPH CLEARANCE ENVELOPE
SHEET 3 OF 4

CONTRACT NO. 13259B
DRAWING NO. TM 3.2.3-C
SCALE 1"=1'-0"
SHEET NO.



SPACE NECESSARY FOR 25kV OVERHEAD CONTACT SYSTEM
FOR CHSTP SECTIONS DEDICATED TO HIGH SPEED
FOR CONTACT WIRE HEIGHT OF 18'-9"
ALIGNMENT IN TUNNEL OR STRUCTURE



SPACE NECESSARY FOR 25kV OVERHEAD CONTACT SYSTEM
FOR CHSTP SECTIONS DEDICATED TO HIGH SPEED
FOR CONTACT WIRE HEIGHT OF 18'-9"
IN TUNNEL OR STRUCTURE FOR SUPERELEVATED TRACK

NOTE:

1. THE 25kV OCS ELECTRICAL ENVELOPE DOES NOT INCLUDE THE NECESSARY SPACE REQUIREMENT FOR THE 25kV NEGATIVE FEEDER WIRE IN PHASE OPPOSITION TO THE 25kV CONTACT WIRE.



REV	DATE	BY	CHK	APP	DESCRIPTION
					07-07-09

DESIGNED BY E. SCOTSON
DRAWN BY J. LAU
CHECKED BY A. MURPHY
IN CHARGE E. SCOTSON
DATE 07-07-09

**PARSONS
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CALIFORNIA HIGH-SPEED TRAIN PROJECT

25kV OVERHEAD CONTACT SYSTEM AND
PANTOGRAPH CLEARANCE ENVELOPE
SHEET 4 OF 4

CONTRACT NO. 13259B
DRAWING NO. TM 3.2.3-D
SCALE 1"=1'-0"
SHEET NO.